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Guide to Resource Conservation and Cost Savings Opportunities in the Plastics Reprocessing Sector

Ministry of Environment and Energy

EPIC
ENVIRONMENT AND PLASTICS INDUSTRY COUNCIL

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Dear Reader:

The Ontario Ministry of Environment and Energy (MOEE) and the Environment and Plastics Industry Council (EPIC) are pleased to provide this copy of the "Guide to Resource Conservation and Cost Savings Opportunities in the Plastics Reprocessing Sector". The guide was prepared jointly by the Ministry and EPIC.

This guide identifies and promotes opportunities for conserving energy and water, as well as reducing waste, in the plastics reprocessing sector. By taking advantage of these opportunities, operators can lower their costs while conserving valuable resources.

Many groups have an interest in further refining plastics reprocessing techniques, including owners, managers and employees, entrepreneurs, product and technology suppliers, engineering designers, and consultants. By combining their own knowledge and skills with the information contained in this guide, these groups can help keep the Ontario plastics reprocessing sector competitive by becoming more efficient and by conserving valuable resources.

We hope this guide is useful to you and your company. We would be grateful to receive any comments or questions you may have about this publication. A form is enclosed so that you can send comments by fax or mail.

You may also contact EPIC at (905) 678-7748 and the Industry Conservation Branch of the MOEE at (416) 327-1454.

George Zegarac

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EXECUTIVE SUMMARY

PURPOSE

The "Guide to Resource Conservation and Cost Savings Opportunities in the Plastics Reprocessing Sector" was prepared to help those involved in reprocessing plastics to identify potential process improvements that will reduce production costs, conserve resources and prevent pollution. It is intended to be a helpful tool that can be used in combination with existing skills and knowledge among clients who share an interest in the plastics reprocessing sector. The Guide is directed primarily to company owners, managers and employees. Other individuals and client groups who would be interested in this Guide include product and technology suppliers, engineering designers, consultants and related associations.

The Guide offers generic process descriptions and checklists of improvement opportunities specific to the major steps used in the complete cycle of plastics reprocessing. Not all companies in Ontario's plastics reprocessing sector include all the steps in their process that are described in the Guide. In addition, each facility has its own configuration that makes it unique. However, any company that handles waste plastic feedstock may find sections of this guide helpful in identifying ways to conserve energy and water and reduce wastes and costs.

Based on Chapter 3, reprocessors should be able to compile a list of relevant technologies or other options that may offer greater process efficiency or resource conservation advantages in their own facilities. Some changes may be implemented immediately at little or no-cost. For other changes, more detailed analysis will be required to assess which options are applicable to a company's specific needs and which should be given priority.

HIGHLIGHTS

Energy Conservation

Melt processing and granulation are usually the highest energy consuming steps in full scale reprocessing, accounting for approximately 40% and 30% respectively of total demand. Potential to reduce energy consumption exists through the installation of high efficiency motors and variable speed drives (typically 5-40% over conventional equipment), the adoption of two-stage size reduction (up to 30%) and proper sizing and improved maintenance of granulation equipment (10-30%). In some applications, the introduction of twin screw extruders can potentially reduce energy consumption in this step by 50-70%. Savings will vary depending on the unique situation and percentages are not necessarily additive.

Water Conservation

Opportunities to conserve water include counter-current washing, filtration and reuse of water at earlier stages of the process, and reuse of cooling water in wash processes. The savings achieved will depend on municipal water and sewer charges and the amount of detergents and surfactants recovered.

Waste Reduction

Because of the unique configuration and type of plastics handled, the waste streams associated with plastics reprocessing are very diverse. A comprehensive waste audit of the overall plant and offices can identify opportunities to consolidate and minimize materials for disposal.

Technology Development Opportunities

There are still technical problems to be overcome in separation by polymer type, colour and molecular weight if end use possibilities are to increase. Multi-resin polymers, laminates, engineered resins and thermoset resins pose a challenge to recyclers since most end users of reprocessed pellets require single resin product streams.

Although many advances have been made in processing equipment, development of improved equipment such as cutting blades and polymer filtering systems are needed to reduce maintenance requirements. This is a major cost for reprocessors. Other areas of research that could improve the viability of reprocessing are cost-effective odour removal, more thorough cleaning technologies and alternative waste disposal methods.

STRUCTURE

Following an introduction to the Guide in **Chapter 1**, **Chapter 2** provides background, a description of the industry in Ontario, and a review of emerging sector issues that may influence its viability in the future.

Chapter 3 — **Generic Process Descriptions and Improvement Opportunities**, provides a description of the main processing steps in a generic reprocessing system, and describes the typical energy, water and material inputs, flows and outputs of such a system. A separate section highlights resource conservation opportunities that are available at each stage of the process. While each facility is different, configured to meet the specific demands of its feedstock and needs of its customers, the generic stages described should be familiar to every reprocessor.

Chapter 4 — **Unit Performance Ratios,** offers a short introduction to the calculation of unit performance ratios, a useful method for assessing and tracking water and energy usage within a facility.

Chapter 5 — **Process Residuals,** addresses environmental and occupational health and safety concerns typical to the reprocessing sector. The issues of air emissions, dust and odour control, wastewater and solid waste disposal, and noise abatement are discussed briefly in relation to statutory requirements.

Chapter 6 **New Technologies,** provides a concise overview of some technologies currently under development or undergoing field testing that will become commercially available to reprocessors over the next three to ten years.

Chapter 7 **Other Helpful Information**, contains an annotated compilation of other publications and information sources for use by companies or individuals interested in pursuing follow-up resource conservation initiatives.

Chapter 8 **Report References**, lists the documents used as source material in preparing this Guide.

Appendix I, **Sourcing Raw Materials**, briefly describes the types and sources of recyclable plastics currently being collected and reprocessed in Ontario. It contains suggestions around the issue of sourcing raw materials which, although not directly related to resource conservation, is of importance in achieving a sustainable enterprise.

Appendix II, **Glossary,** consolidates and defines many of the acronyms and terms used throughout the guide.

Follow up Services Available

The Industry Conservation Branch (ICB) of the Ministry of Environment and Energy can provide assistance to companies developing a resource conservation plan. Utility bill analysis is a service offered to Ontario companies as the first step in conducting a resource use assessment of a plant. The analysis provides a quick indicator of an individual company's energy and water consumption patterns and the efficiency of operations. Immediate savings can often be identified in the analysis of gas, electricity, oil and propane, and water consumption patterns. A follow-up plant "walk-through" analysis identifies potential operational savings in energy, water and other process-related resource use in the facilities. Companies can then pursue resource conservation opportunities using their own technical staff or with the assistance of an external consultant. Contact the Industry Conservation Branch at (416) 327-1453 for more information on these services.

ACKNOWLEDGEMENTS

The development of this guide was jointly sponsored by the Ontario Ministry of Environment and Energy (MOEE) and the Environment and Plastics Industry Council (EPIC, formerly known as the Environment and Plastics Institute of Canada and now a Council of the Canadian Plastics Industry Association). EPIC is an industry initiative committed to the responsible use and recovery of plastic resources.

We wish to acknowledge the work and effort of the following organizations and private firms in providing valuable information, technical input and comments throughout the development of the guide. We are grateful to the members of the Steering Committee who have made themselves available throughout the project:

- Fred Edgecombe and Cathy Cirko, EPIC
- Dave Thomson, Canadian Polystyrene Recycling Association
- Jim Horn, Resource Plastics Inc.
- Ray Arseneault, NOVA Chemicals Ltd.
- John Bolan, Ministry of Economic Development, Trade and Tourism (MEDTT)
- Dennis Onn and Trish Bolton, Ministry of Environment and Energy (MOEE)

The Steering Committee also wishes to thank Bill Glenn of W.G. Glenn Environmental Consultants for his skill and effort in preparing this document.

MOEE and EPIC encourage the distribution of information and strongly support the concurrent promotion of pollution prevention and industrial competitiveness in Ontario. Measures to support pollution prevention include the conservation of industrial resources, such as energy and water, as well as the reduction of waste. Any person who wishes to republish part or all of this report should notify the Ontario Ministry of Environment and Energy, Communications Branch, 135 St. Clair Avenue West, Toronto, Ontario, Canada, M4V 1P5.

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1.0 INTRODUCTION

PURPOSE

The "Guide to Resource Conservation and Cost Savings Opportunities in the Plastics Reprocessing Sector" was prepared to help those involved in reprocessing plastics to identify potential process improvements that will reduce production costs and conserve resources. The Guide is intended to be a tool that can be used in combination with existing skills and knowledge among clients who share an interest in the plastics reprocessing sector. Individuals and groups interested in this Guide could include company owners, managers, employees, product and technology suppliers, engineering designers, consultants and related associations.

The Guide offers generic process descriptions and checklists of improvement opportunities specific to the major steps used in plastics reprocessing. The major process areas covered are:

- receiving and bale breaking
- size reduction
- pre-washing
- contaminant separation
- flotation and separation
- melt processing
- inspection and sorting
- ferrous metal separation
- granulation
- washing and dirt removal
- dewatering and drying
- packaging and shipping

Not all companies in Ontario's plastics reprocessing sector include all these steps in their process. In addition, each facility has its own configuration that makes it unique. However, any company that handles waste plastic feedstock may find sections of this guide helpful in identifying ways to conserve energy and water and reduce wastes and costs.

HOW TO USE THIS GUIDE

A reprocessor who wishes to explore resource conservation opportunities should pay particular attention to Chapter 3. It summarizes and assesses initiatives that have been used successfully by other reprocessors to cut energy and water use, reduce waste disposal charges and improve resin quality.

Table 4, "Generic Process and Utility Improvement Opportunities" and Table 5, "List of Applicable Energy Saving Techniques" can serve as useful checklists that summarize available options. Table 4 also cross-references the relevant sections for the guide in which the options are discussed.

Next Steps
Based on Chapter 3, a reprocessor should be able to compile a list of relevant technologies or other options that may offer greater process efficiency or resource conservation advantages at his own facility. Some changes may be implemented immediately at little or no-cost. For other changes, more detailed analysis will be required to assess which options are applicable to a company's specific needs and which should be given priority.

The Industry Conservation Branch (ICB) of the Ministry of Environment and Energy can provide assistance to companies in developing a resource conservation plan. Utility bill analysis is a service offered to Ontario companies as the first step in conducting a resource use assessment of a plant. The analysis provides a quick indicator of an individual company's energy consumption patterns and the efficiency of operations. Immediate savings can often be identified in the analysis of gas, electricity, oil and propane, and water consumption patterns. A follow-up plant "walk-through" analysis identifies potential operational savings in energy, water and other process-related resource use in the facilities. Companies can then pursue resource conservation opportunities using their own technical staff or with the assistance of an external consultant. Contact the Industry Conservation Branch at (416) 327-1453 for more information on these services.

2.0 SECTOR PROFILE

2.1 Background

Plastic reprocessors are in the waste reduction business. They divert valuable post-industrial and post-consumer resins from disposal, while producing a product that can compete in terms of both price and quality with virgin resins. In doing this, plastic reprocessors face four major production expenses: labour, energy use, water use, and waste disposal. Those able to operate most efficiently, conserve energy, cut water use and reduce wastes, are best positioned to compete in the tough plastics market. This report describes a number of short and long-term opportunities available to the plastics reprocessing sector for conserving resources and reducing production expenses.

Manufacturers have been recycling their own plastic scrap, flash, trim and rejected parts — commonly known as regrind — in-house for many years. Mixed with virgin resins, regrind was (and is) loaded back into the system and extruded or remolded into another plastic product. When processors had more regrind than they could use in-house, this material might be sold to a broker or plastic reprocessor who could also be recycling dry, clean, single resin scrap from compounders, converters, packagers and distributors.

Beginning in the 1970s, the first attempts to recycle post-consumer resins (PCR), such as empty milk jugs or used bags, were undertaken. This was a period of rapidly rising resin prices following the OPEC oil embargoes. For a time and on a local scale, these efforts were moderately successful. However, the lack of stable markets for recycled PCR, technological inadequacies, uncertain supplies of quality feedstock, and falling prices for virgin resins conspired to derail these initiatives.

As recently as 1987, there were no companies recycling post-consumer resins in Ontario, although several firms continued to reprocess clean industrial scrap. Since then, a number of factors — including rising disposal costs, increased public pressure and growing emphasis on waste diversion — have refocused attention on plastics recycling opportunities. In addition, supplies of plastic wastes have been boosted by legislated recycling programs in the industrial, commercial and institutional sectors, as well as residential collection programs operated by municipalities.

The recycling industry currently operates in the "pinch point" of the hour glass, poised between vast, largely untapped supplies of waste plastics and large potential markets for reprocessed resins. A number of reprocessors have been able to penetrate general resin markets and compete with producers of virgin resins on the basis of both cost and quality. However, the plastics market is a commodities market and reprocessors must continually wrestle with fluctuating prices and uncertain markets for the resins they handle.
In recent years, slumping prices and an oversupply of virgin resins have precipitated the closure of a number of reprocessors. Others, that have been able to operate

more efficiently, cut costs and access stable sources of supply and viable after-markets, have entered the field and achieved moderate financial results.

2.2 The Plastic Reprocessing/Recycling Sector in Ontario

Ontario's reprocessing sector has the capability of recycling all the basic commodity resins including low density and linear low density polyethylene (LDPE and LLDPE), high density polyethylene (HDPE), polystyrene (PS), polypropylene (PP) and polyvinyl chloride (PVC). As well, reprocessors have the capability to recycle some engineered resins.

Polyethylene terephthalate (PET) is not reprocessed in Ontario, although it is collected in Ontario's curbside recycling programs. PET reprocessing entails a very high capital investment and must operate at millions of kilograms of capacity if it is to be accomplished economically. As a result, both sources and end-use markets for reprocessed PET are pursued on a North American basis. Reprocessing of PET is primarily undertaken in the U.S. although some facilities exist in Quebec for producing flake.

All of the major resin groups listed above are classified as thermoplastics. They can be repeatedly reheated and reshaped and, therefore, are readily recyclable. Thermoset plastics undergo an irreversible chemical reaction in the process of hardening and cannot be remelted and reformed using current technology. This guide does not address the reprocessing of thermosets.

Statistics on the plastic reprocessing industry in Ontario are complex. EPIC estimates that, in 1996, at least 65 companies operating in Ontario handle waste plastics. These companies employ as many as 1,300 workers. They vary greatly in the waste plastic handling, recycling and reprocessing services offered. Companies may be categorized into those that:

- consolidate and broker materials from material recycling facilities (but do little in the way of materials handling);
- sort the feedstock into specific resin streams and bale for further processing elsewhere;
- shred feedstock (or densify, if necessary) to reduce the shipping volume;
- reprocess post-industrial scrap directly into flakes or pellets (without washing and drying);
- manage commingled plastic feedstock (converting them, without cleaning, into "plastic lumber" or similar products); or
- have the full capability to sort, shred, wash, dry and extrude feedstock (post-industrial and/or post-consumer resins) into pellets.

This guide is directed primarily at companies in the final full capability category. However, any company that handles waste plastic feedstock may find sections of this guide helpful in identifying ways to conserve energy and water and reduce wastes and costs.

2.3 CURRENT ECONOMIC STATUS

There is little published economic information available on the plastics reprocessing sector. Companies tend to be privately held and public disclosure of financial data is limited. Due to the highly competitive nature of the business, most companies protect their sources of raw materials, customers and markets, resin outputs, capacities and other processing details.

The sector comprises companies of all sizes and levels of sophistication, ranging from large, modern facilities to much smaller shops. In general, companies that offer the full range of reprocessing services operate larger plants and serve clients and markets across North America. Their feedstocks are sourced in Canada and the U.S., and their products are used in both domestic and international markets.

Currently, there is a degree of stability in the plastics commodities markets. As a result, the reprocessing sector has grown. It will continue to grow as, and if, new markets and new processes are developed. Full capability plastics recycling is highly competitive and requires significant up-front capital investment. Any investor will need strong financial resources available for an extended period to become successfully established and achieve a reasonable return.

2.4 RELEVANT LEGISLATION, REGULATIONS AND STANDARDS

Table 1 lists and describes the environmental regulations that may apply to the operation of plastic reprocessing facilities. More information is available from the regional offices of the Ministry of Environment and Energy (MOEE) listed in the blue pages of the telephone directory.

In addition, reprocessors must comply with a number of provincial regulations under the Occupational Health and Safety Act that address occupational exposure limits, the use of personal protective equipment, certification training, and other relevant topics. Information and copies of the Occupational Health and Safety Act are available from area offices of the Ministry of Labour (MOL) listed in the blue pages of the telephone book.

TABLE I
SUMMARY OF ENVIRONMENTAL REGULATION RELEVANT TO THE PLASTICS REPROCESSING INDUSTRY

TOPIC		LEGISLATION, REGULATION, GUIDELINE	JURISDICTION	ADMINISTERING AGENCY	PURPOSE
All Potential Discharges		EPA Certificate of Approval	Provincial	MOEE	Control of discharges to the environment
Waste Management, General		EPA Regulation 347	Provincial	MOEE	Control of waste management systems including hazardous and industrial wastes
3Rs		EPA Regulation 347	Provincial	MOEE	Exemption of recyclable materials from EPA
		EPA Regulation 101/94	Provincial	MOEE	Requirement for municipal residential recycling programs Exemption of recycling facilities from approval procedures
		Regulation 102/94*	Provincial	MOEE	ICI waste auditing and reduction
		Regulation 103/94*	Provincial	MOEE	ICI source separation
		Regulation 104/94*	Provincial	MOEE	Packaging audits and reduction
Air	Particulates	EPA Regulation 346	Provincial	MOEE	Control of emissions (dryer exhaust)
	Odour		Provincial	MOEE	Control of odours
Effluent	Direct Discharge	Fisheries Act	Federal	MOEE	Control of discharges to receiving bodies of water
		Ontario Water Resources Act	Provincial	MOEE	Control of discharges to receiving bodies of water
		Environmental Protection Act	Provincial	MOEE	Control of discharges to receiving bodies of water
	Sewer Discharge	EPA Regulation 358	Provincial	MOEE	Control of Sewage Systems
		Municipal Act	Provincial	Municipality	By-Laws to control municipal sanitary sewer discharges

* Reprocessors are not subject to these regulations. However, such regulations have a potential effect on feedstock supply and markets.

2.5 EMERGING SECTOR ISSUES

Economic Sustainability:
A 1994 report, "Defining A Plastics Diversion Strategy," prepared by a multi-stakeholder strategy team[1] concluded that:
"Almost all the identified barriers (to plastics diversion) have an economic component: from the undervalued cost of landfilling and other disposal alternatives ... to the current economics of and cost allocations for plastics collection, separation and recycling ... to the markets for the recovered resins and their ability to compete with virgin and off-grade resins. Other barriers may be regulatory, technical or even perceptual."

According to the strategy team report, a "viable (plastics) recycling program depends on four components: (1) a dependable supply of high quality, used plastic feedstock, (2) an efficient and cost-effective collection system, (3) a healthy recycling industry, and (4) firm markets for the recycled resins." Unless all four of these conditions are met, the recycling of industrial scrap and post-consumer resins is not economically sustainable.

While progress has been made, especially in the areas of technology development and collection infrastructure, there are still major problems that must be overcome in the areas of supply and markets to satisfy these four prerequisites for a healthy recycling sector.

Feedstock Supply:
In the IC&I sector, many generators are unaware of the opportunities for plastic recycling. In the residential sector, household access to plastics recycling is growing. However, not all Ontario municipalities collect plastics to the same extent, other than PET bottles.

In both these cases, the resulting missed opportunity to access the potential supply of PCR may affect the economics of reprocessing operations. Plastics reprocessors require an assurance of consistency of supply in both quality and quantity of feedstock materials to recycle plastics cost effectively.

The Role of Material Recycling Facilities (MRFs):
The MRFs are a key player in ensuring the quality and quantity of feedstocks available to reprocessors. The condition of materials received by the reprocessor can have a significant impact on the resource inputs required to produce a quality product. If the reprocessing industry is to grow significantly, there is a need to establish more stability in the relationship between MRFs and reprocessors. In a longer term arrangement, conditions may allow for the possibility of MRFs providing a flaked material which would have the benefit of eliminating baling and reducing freight and handling costs.

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[1] The multi-stakeholder strategy team had representatives from the plastics industry, municipal and provincial governments, MRF operators, and environmental groups. It was convened by the Waste Reduction Branch of MOEE to identify barriers to and opportunities for diverting more plastic from disposal.

In the U.S., major producers of recycled resin have begun to enter into long term contracts with MRF operators and communities to ensure feedstock supplies. Such agreements can ensure security of supply, control of quality and continuity of pricing. This practice is not currently widespread in Ontario. However, the existence of such agreements could strengthen the Ontario industry and represents a business development opportunity in the evolution of plastics recycling.

Technology Research and Development:
There are still technical problems to be overcome in separation by polymer type, colour and molecular weight if end use possibilities are to increase. Multi-resin polymers, laminates, engineered resins and thermoset resins pose a challenge to recyclers since most end users of reprocessed pellets require single resin product streams.

Although many advances have been made in processing equipment, development of improved equipment such as cutting blades and polymer filtering systems are needed to reduce maintenance requirements. This is a major cost for reprocessors.

Other areas of research that could improve the viability of reprocessing are cost-effective odour removal, more thorough cleaning technologies and alternative waste disposal methods.

Development of Research Alliances
More cooperative research based on strategic alliances between the plastics industry, its customers and other industry players is one vehicle that could be effective in solving specific problems. For example, in the automotive sector, issues such as uses or treatment of auto fluff, recovered packaging and manufacturing waste affect both automobile companies and plastics reprocessors. Similarly, in the pulp and paper sector, waste recovered from hydropulping of precoated board stock contains both fibre and plastic that could potentially be reused. Bringing together the expertise and resources of the players to focus on economically viable approaches would benefit both waste producers and reprocessors.

Resin Pricing and Markets:
The development of markets for post-consumer resins has not kept pace with the growing capacity of the recycling infrastructure. Potential users of reprocessed resins often associate a risk to process equipment or final product quality with the use of PCR as an input. To lessen this risk perception, barriers to the use of PCR, such as product specifications that demand the use of virgin resins, may be raised. As a result, PCR resins rarely compete with virgin resins for market share. In cases where PCR can be substituted, recycled resins generally command a price that is lower than virgin resin.

Procurement Policies:
With few exceptions, products containing PCR are not accorded preferred or preferential status in the procurement policies of the public (i.e. federal, provincial or municipal) sector or private sector companies in Canada. Certain U.S. states require or give preference to products that contain a certain percentage of PCR. Introduction of procurement policies that support the purchase of products certified to contain the highest level of PCR that meets product specifications is an area where government and major industry buyers need to provide leadership.

3.0 GENERIC PROCESS DESCRIPTIONS & IMPROVEMENT OPPORTUNITIES

Each plastics reprocessing line is product-specific, designed to accommodate the expected quantity, quality and type of resins to be recycled. As a result, there will be significant variations in processing conditions, water and energy use and waste production depending upon the specific operations of each facility. While the processing order may vary from plant to plant, and not all facilities undertake each of these operations, a complete plastics reprocessing line would likely entail the generic steps listed below and illustrated in Chart I.

Stage I: Preprocessing

Step
1. receiving and bale breaking
2. inspection and sorting
3. size reduction (shredding)
4. ferrous metal detection and separation
5. pre-washing

Stage II: Processing

6. granulation
7. electrostatic, magnetic and air-forced separation
8. washing and dirt removal
9. flotation and/or hydrocyclone separation
10. de-watering and drying

Stage III: Finishing

11. melt processing
12. PCR packaging and shipment

Chart 2 illustrates typical energy and water consumption points, as well as the wastewater, solid waste generation and environmental emission points. Table 2 outlines the approximate distribution of all forms of energy demand within the facility. Table 3 breaks down the electrical power requirements of a generic reprocessing facility. Table 4 summarizes the generic process steps, the related conservation opportunities and directs the reader to the section of the guide where the opportunities are discussed. Finally, Table 5 identifies the level of energy savings that may be achieved through the use of specific technologies.

CHART 1 - GENERIC PLASTICS REPROCESSING FACILITY

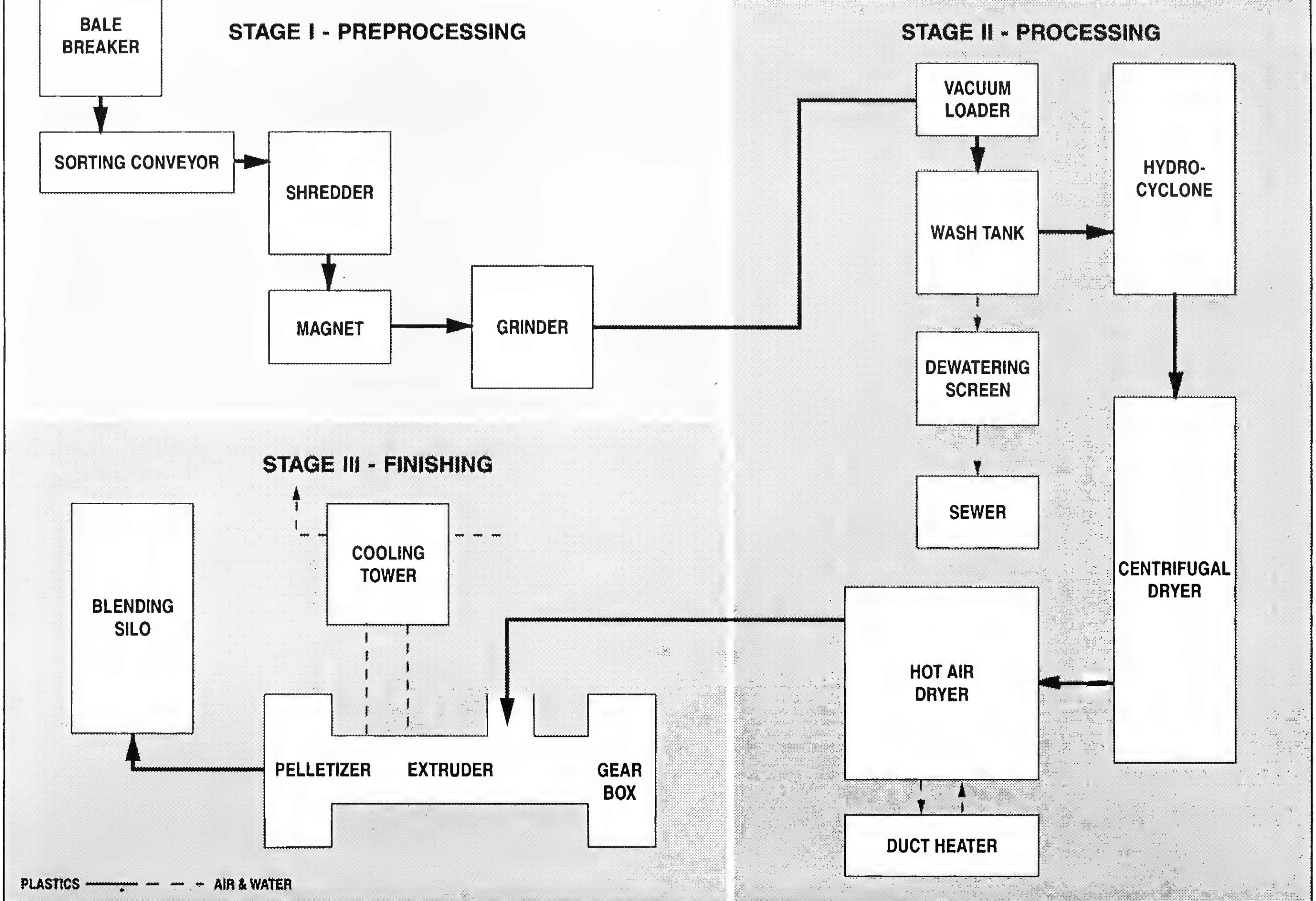
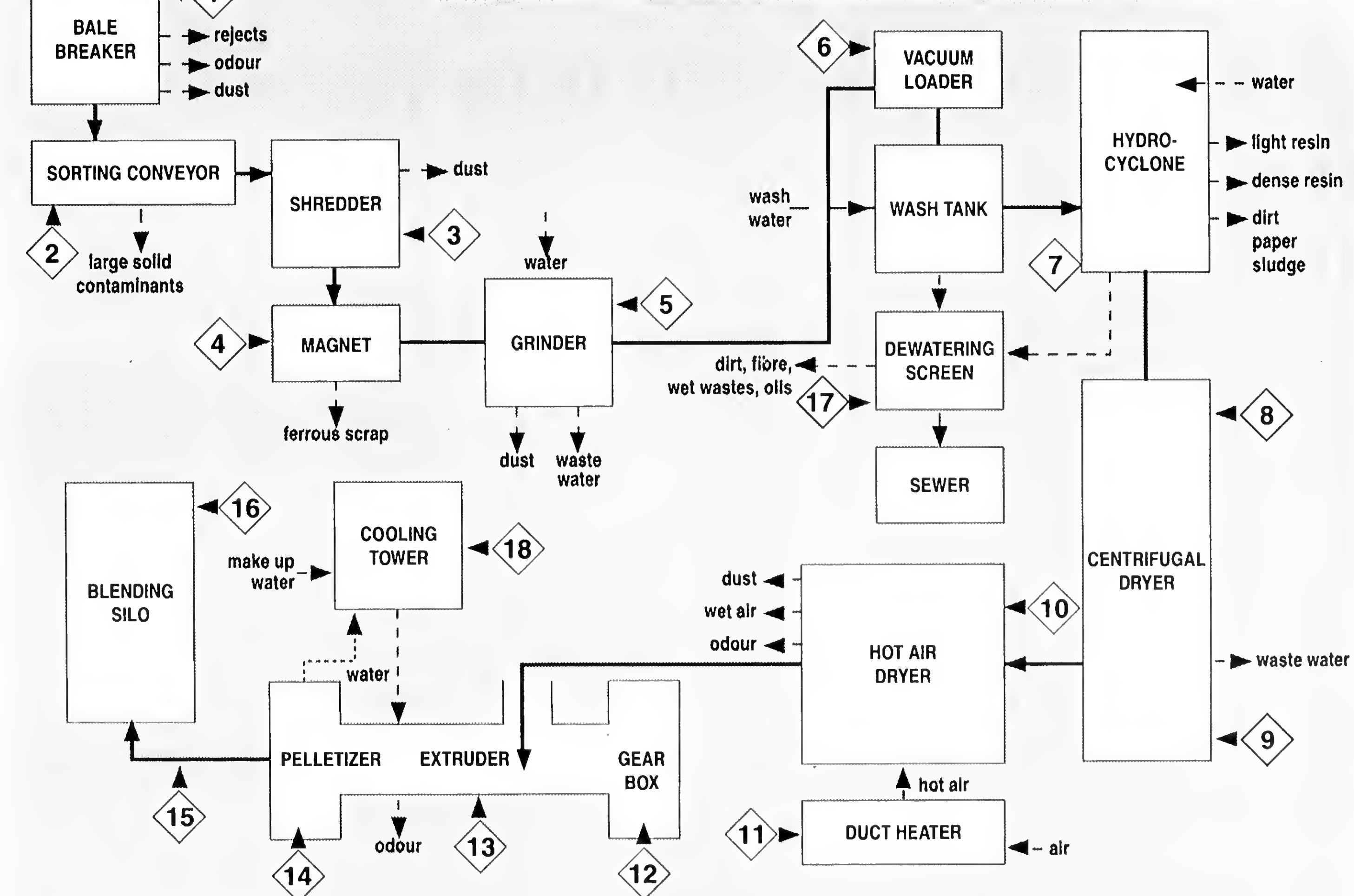


CHART 2 - RESOURCE CONSUMPTION & EMISSION POINTS



PLASTICS ← ◇ ELECTRICITY INPUTS (NUMBER CORRESPONDS TO CODE ON TABLE 3)

Table 2
APPROXIMATE DISTRIBUTION OF TOTAL ENERGY DEMAND

Process Area	Percentage of Total Demand
Extruder	40
Granulators	30
Material drying	10
Material handling	10
Miscellaneous	10
TOTAL	100

Table 3
ELECTRIC POWER REQUIREMENTS

Code (chart 2)	Process Operation	Typical Demand* (in kilowatts, kW)	Percentage of Total Load
1	Bale breaker motor	7.5	1.0
2	Conveyor motor	2.0	0.3
3	Shredder motor	40.0	5.3
4	Conveyor motor	2.0	0.3
5	Grinder motor	100.0	13.2
6	Vacuum pump motor	12.0	1.6
7	Pump motor	7.5	1.0
8	Blower motor	5.0	0.7
9	Dryer motor	12.0	1.6
10	Blower motor	13.8**	1.8
11	Blower motor	13.7**	1.8
12	Extruder motor	300.0	39.6
13	Extruder heater	180.0	23.7
14	Pelletizer drives	7.5	1.0
15	Pellet blower	7.5	1.0
16	Blender motor	15.0	2.0
17	Rotary screen motor	3.0	0.4
18	Pump & blower motors	30.0	4.0
	TOTAL	758.5	100.0

* based on a plastic feed rate of 600 kilograms per hour
** average of range 7.5 - 20 kW

3.1 Receiving & Bale Breaking

3.1.1 Description

In most cases, feedstock arrives at the reprocessing plant in bales pre-sorted into basic resin types and colour groups. Contaminants, including dirt, broken glass, metals, paper and other materials, may have been introduced during curbside collection, transport and sorting/baling at the MRF. At this point, shipments that do not conform with the specifications of the recycling facility may be rejected and returned to their point of origin, usually at the expense of the generator.

Guillotines may be used to break apart or separate large pieces that have been fused or meshed together — such as film rolls and heavy plastic chunks — prior to shredding and/or granulation. Guillotines may also be used to precut film that would otherwise clog shredding or granulating units. In some cases, a table saw is used to cut large pieces of scrap into more manageable sizes.

Some packaging and transport wastes are generated during receiving and bale breaking, including baling materials, wire bands, film wrappings, shipping boxes and pallets. Containers and large scrap pieces composed of unacceptable resins may also be removed prior to shredding/granulation.

3.1.2 Opportunities

Recycling:
Packaging and shipping waste should be quantified and assessed with respect to ease of separation and recyclability. Diversion of these waste streams to possible end users can decrease waste disposal costs. A waste audit of the complete facility is a valuable exercise to identify and consolidate similar waste streams that might be diverted.

Noise, Odour and Dust Reduction:
Control measures can involve segregating and/or insulating the debaling equipment. Employees should also be supplied with personal protective equipment and instructed in its proper use. Sections 5.2, 5.3 and 5.6 discuss dust, odour and noise control.

3.2 Inspection & Sorting

3.2.1 Description

Successful plastic recycling depends on proper resin sorting. Even relatively small amounts of certain resins, unless they are removed, can ruin the recyclability of the primary plastic feedstock. At the reprocessing facility, separation of resin and colour type usually begins with the manual inspection of the feedstock and the removal of major contaminants.
Contaminants mixed in with the feedstock may include: dirt and stones, caps,

labels and other packaging components, printing inks and adhesives, and product residues and food wastes in bottles and containers. At this stage, grossly contaminated containers, items that are obviously of the wrong resin grade or colour, and other readily recognizable contaminants can be removed, usually by hand, and reserved for recycling or disposal.

There are a number of electronic, mechanical and automated separation technologies being tested at the bench or pilot scale or offered on a commercial basis. These are briefly summarized in Section 6, New Technologies.

3.2.2 Opportunities

Recycling:
The make-up of each solid waste stream should be quantified and assessed as to its recyclability. This would normally be documented during a facility waste audit. Recycling potential will be affected by ease of separation and availability of markets. The waste exchanges and bulletin boards described in Appendix I of this guide may assist in identifying outlets for recovered material. Negotiations with suppliers to upgrade raw material specifications to reduce the proportion of off-spec materials could also be undertaken.

3.3 Size Reduction (Shredding)

3.3.1 Description

Shredders are used to reduce the feedstock components to a size that facilitates further processing. The decision to shred (as opposed to using alternative size reduction techniques such as granulating or pulverizing) depends on the type of material, physical characteristics, contamination level present in the raw feedstock and permitted in the final recycled resin, extruder design and capabilities, and other end-use considerations.

Shredders are suitable for handling bales, large hollow bodied containers, cables, bumpers, purgings and larger scrap pieces. Screw shredders may be used to reduce bulky products, such as sacks or foam parts. Many shredders are equipped with a ram feeder to push material into the unit. They typically reduce feedstock items into pieces of one-to-three inches in length.

Shredders may be equipped with either two or four counter-rotating cutting shafts running at speeds of 5 to 200 rpm. The cutting rings with their hooked protrusions intermesh, gradually pulling plastic scrap in between the knives, ripping and shearing larger items into smaller pieces. Low speed, high torque shredding (as opposed to the high speed, low torque cutting found in granulators) is efficient and minimizes the amount of material being thrown back out of the unit. In addition, shredders are typically less noisy and produce less dust than granulators.

Film is more effectively handled in the primary cutting stage by a guillotine. Reprocessors handling loose scrap film, shrink wrap, bags and similar low

density feedstock may also employ a densifier for ease of shredding. However, the material must be cleaned first to avoid dirt entrapment.

3.3.2 Opportunities

Shredder Design:
Correctly matching the shredder design to the characteristics of the feedstock will improve the efficiency of operation and the associated resource conservation benefits. Although shredders are available in a variety of sizes, the choice of blade style and drive type are the major variables in shredder design. The number of hooks, hook height and blade width are all dictated by the types of wastes the unit is expected to shred. More hooks, for example, make it harder to grab a larger piece of scrap, and thin knives produce finer shreds but require a larger drive. Efficiency can be improved by equipping the separate cutting shafts with separate drives operating at different speeds, usually a differential of 10-20%.

Blade Design:
Blade wear and maintenance are major cost areas. Shredder disks and blades made of tougher alloys will reduce wear and replacement costs.

Two-Stage Size Reduction:
Consideration should be given to two-stage size reduction. In this process, the scrap, containers and other wastes are shredded first into chunks prior to the magnetic removal of ferrous scrap. Next, the chunks are granulated or pulverized into much smaller flakes, chips or granules to facilitate washing and contaminant separation prior to melt processing.

The benefits of two-stage size reduction are energy efficiency, i.e. achieving greater output per unit of electrical energy, and cost efficiency. For example, a 20 horsepower (hp) shredder and a smaller, less costly 15 hp granulator together can typically replace a 100 hp granulator. Pre-shredding also saves wear and tear on the granulator, extending blade life by a factor of three or four times. While a large, solid chunk of plastic might bounce around over the cutting knives of a granulator, slowly being chipped away, it would be ground down more efficiently in a shredder. It is estimated that potential energy savings of up to 30% may be made using two-stage shredding.

For high volume operations, a very large, efficient granulator may have a lower initial capital cost and be more cost effective than several, smaller shredder/granulator combinations. Initially, the grinder alone may be approximately 20% less expensive initially than a dual system. However, the capital cost savings may be more than offset by higher operating, maintenance and downtime costs over the life of the equipment.

Microprocessor Controls:
Reduction in energy use can be achieved through the use of automatic shut off switch on size reduction equipment when the machine is not in use.

3.4 Ferrous Metal Removal

3.4.1 Description

Conveyor belts leading to the granulator may be equipped with magnetic head pulleys to remove ferrous metals. Systems may also employ overhead belt magnets, drum magnets or one of a variety of other commercially available permanent magnet devices. There are a number of vendors that can assist in the selection of an appropriate system based on factors such as size and quantity of the contaminants, desired throughput rate, available space and budget.

3.4.2 Opportunities

Recycling:
Ferrous contaminants may be separated and reserved for recycling or disposal. The generation of ferrous waste throughout the facility should be quantified and assessed as to its recyclability, if this is not already being done.

3.5 Pre-Washing

3.5.1 Description

Non-ferrous materials, glass, stones, and minerals may be removed in a pre-wash process that takes advantage of the difference in specific gravity of materials to effect separation of these contaminants. Water is the least expensive and most common fluid used in this process. Pre-washing reduces the load on the primary wash system and minimizes the risk of damage to the grinder from foreign objects. Because of the level of contamination of the pre-wash water, it is generally not reused anywhere in the process. In specific situations where high water costs or sewer surcharges exist, the cost of filtration, treatment and reuse of prewash water may be justified.

3.6 Granulation

3.6.1 Description

Granulators prepare the feedstock for melt processing by reducing it to flakes, chips or granules, typically one-eighth to one-quarter inch (or larger) in size. Granulators consist of a loading hopper, cutting chamber (with knives mounted on a rotor), screen, and drive mechanism. Two- or three-blade rotors are the most common, with the rotating knives cutting against a stationary bed of knives. The shaft rotates at speeds of 600 to 1,300 rpm and runs with low torque at high speeds.

Granulators may also be equipped with a feeding device such as an auger or counter-rotating rollers. All granulators should incorporate safety features that prevent feedstock from flying back and that deny operator access to an active unit.

During granulation, the feedstock undergoes intensive agitation that promotes the removal of some of the contaminants that stick to the scrap. Wet granulation, using hot or cold water and, in some cases, detergents, softens and separates paper and plastic labels, adhesives and other contaminants. This process promotes decontamination of the process material and minimizes downstream blockage of screens. Wet granulation also reduces the potential degradation of thermoplastics by the frictional heat generated during cutting and feedstock handling.

Screens are used to ensure a uniform flow of resin particles that meet the required size limits. Larger pieces of plastic are retained in the unit until they are ground to the required size. Following wet grinding, a dewatering screw removes the granulated material from the unit.

In cases where contamination levels are not substantial, or primary washing processes are highly effective, it is possible to replace wet granulation with a dry grinding process. Corresponding savings in energy and water consumption are realized.

3.6.2 OPPORTUNITIES

Granulator Size:
Selection of the proper sized granulator, suitable to the type of scrap to be handled, and the corresponding motor horsepower may produce energy savings of 10-30%.

Granulator Design:
The number, type and mounting of knives, rotor configuration, and other design considerations affect process efficiency, energy use and noise levels. For example, a double angle cut, for which both the rotor and the fixed stator are angled, produces a shearing, drawing cut similar to that achieved with a pair of scissors. The advantages are a lower noise level, reduced power consumption, and less knife wear. The use of an adjustable deflector wedge (an extra cutter) may also make the equipment more versatile and improve through-put rates.

Two-Stage Size Reduction:
For a discussion of the advantages of shredder/granulator combinations, see Section 3.3.2.

Blade Design:
Granulator blades are available in a variety of steels. Selection of the correct metallurgy will provide the best combination of toughness, abrasion and shock resistance for specific resin types. Proper selection of blade steel will minimize maintenance and replacement cost. Blade coatings and cryogenic treatments are available and may extend service life of the blade in some applications.

Maintenance:
Modern granulators allow variation of rotor speed and the precise adjustment of rotor knives and counter-knives. Some processors keep in-house facilities to resharpen cutting blades on shredders and granulators to reduce blade replacement costs and improve process efficiency. Some granulators may use a jig to ensure the proper alignment when installing newly sharpened knives. Improper reinstallation will result in increased wear and possible equipment failure. Currently, even state of the art blades must be replaced frequently, depending upon the plastic being reprocessed. Resharpening and remounting involve considerable downtime. This is an area where research and development is urgently needed and represents a business development opportunity for the equipment supply industry.

Microprocessor Controls:
Some granulators have an automatic shut-off switch designed to save energy when the machine is not in use. This is an area that is undergoing rapid change as new chip-based controllers evolve.

Water Conservation:
The water used in wet granulation may be filtered and reused for prewashing.

Cryogenic Processing:
If a free flowing powder is required, low-temperature, cryogenic grinding using liquid nitrogen may be employed to deep freeze plastic feedstock to temperatures as low as -200° C. This allows the efficient separation of contaminants, such as coatings, layers, glues and labels, for subsequent removal. Dirty pails, for example, can be turned over and tapped or vibrated to remove 98 to 100% of residual paints, adhesives or other contents.

Generally, cold grinding is installed as a retrofit, drilling holes in a granulator and adding nitrogen pipes. Because granulating at low temperatures takes less energy that at room temperature, throughput can be improved or a smaller granulator can be employed.

Cryogenic processing also eliminates any thermal degradation of heat-sensitive resins. The scrap can be shattered and ground, the pulverized resins screened and the coarse fraction (particles larger than 0.3 millimetres) returned for further pulverizing. Despite the apparent advantages, cryogenic processing is a very expensive operation and is usually reserved for reprocessing high value resins.

3.7 Electrostatic, Magnetic & Air Forced Separation

3.7.1 Description

Following granulation, many reprocessors install one or more contaminant separation units to remove the small chips of paper, some of the lighter incompatible plastics, aluminum and other metals. The most common methods used are as follows:

- electrostatic separation uses electric fields to charge and remove aluminum and other metal particles from the feedstock;
- inductive metal detectors are capable of locating very small metal particles, although a sizable number of plastic granules may also be removed with the contaminants;
- either permanent magnets or electromagnets, in the form of grids, cascades or installed in pneumatic tubes, may be used to remove fine particles of iron, steel and other ferrous alloys. The magnets are cleaned automatically when the grid is demagnetized; and
- air classification using cyclones, vibrating screens or automatic air cushion conveyers may be used to remove loose dirt, paper and lighter fractions.

3.7.2 Opportunities

Recycling:
Separation of solid contaminants from the desired polymer feedstock may provide further recycling opportunities. Aluminum, other metals, and certain polymers could be present in sufficient quantities to be considered as recyclable streams in their own right. Waste disposal could be avoided and, potentially, revenue could be generated through proper segregation and handling.

3.8 Washing & Dirt Removal

3.8.1 Description

A plastics reprocessing cleaning system may include a series of mixing drums, one or more washing tanks, centrifugal pumps and hydrocyclones to complete the decontamination process prior to melt processing.

Washing with detergents, surfactants or other cleaning agents loosens the remaining food, dirt, stuck-on labels, adhesives and oils. Intensive agitation is used to wash the flakes or granules, liberate contaminants, separate adhesives, and disintegrate paper into fibres.

Each processor sets his or her own specifications for water temperature, surfactant/detergent concentration and washing time to optimize contaminant separation and removal.

The resin and wash slurry flows to a screening device. The resin flakes remain on the surface of the screen while contaminants such as fines, fibres, soil, dissolved solids and water containing any residual detergent or surfactants are rinsed away. The contaminants are removed and held for disposal.

The rinsed resin may be flushed to a second agitated slurry tank and pumped to a hydrocyclone device or flotation tank.

3.8.2 Opportunities

Water Conservation:
Counter current washing systems may be employed in reprocessing lines using more than one washing tank. The relatively clean rinse water from downstream tanks is used to augment the wash water in the upstream tanks where the dirtiest feedstock is being cleaned. Counter current washing is a widely accepted pollution prevention technique that conserves detergent, reduces water consumption and, if warm/hot washes are mandated, reduces energy use.

3.9 Flotation & Hydrocyclone Separation

3.9.1 Description

Flotation tanks and/or hydrocyclones may be used when it is necessary to obtain pure resin streams. This technique separates the lighter, floating resins from heavier resins and other contaminants by virtue of their respective specific gravities. Agitation and the addition of chemical surfactants to a flotation tank can improve separating efficiency. It is more difficult to separate resins with similar specific gravities than those with significantly different specific gravities.

For example, when processing mixed plastics, the heavy fraction would typically contain PS, PVC, PET and other heavier resins, as well as any residual metal chips, dirt and paper pulp. This material sinks to the bottom of the tank from which it is automatically dredged out for dewatering and possible resale or disposal.

The light fraction would consist of lighter resins such as PE and PP. Both these materials have a specific gravity less than 1.0 (water). The clean material is mechanically dewatered before it is conveyed to a drying oven and, if necessary, a dehumidifier.

3.9.2 Opportunities

Solid Waste Recycling:
The unwanted resins can be separated, dewatered, dried and held for disposal or recycling in a mixed plastic product such as plastic lumber. Dirt and paper sludge may be dewatered prior to composting or disposal.

Oil Recycling:
Dirty oil emulsified by the detergents used in the wash cycle must be removed from the rinse water before it can be reused in the pre-wash stage. A number of gravity-based oil-water separators are commercially available. If sufficient quantities of oil are recovered, consideration may be given to recycling it.

Water Conservation:
The wastewater can be filtered and used for washing or pre-washing before discharge provided that chemical surfactants have not been added.

3.10 De-Watering & Drying

3.10.1 Description

Dewatering may be done with centrifugal dryers, followed by thermal dryers that may incorporate dehumidifiers to reduce the final moisture content to a level dictated by the particular resin stream and process equipment. Higher drying capacity is required for hygroscopic resins such as PET, film and foam. Reprocessors handling condensation polymers (PET, etc.) should note the special drying requirements of those materials.

To provide good drying conditions, a dryer should provide: adequate drying temperature and dewpoint for the quantity of air used; adequate residence time for all the resin passing through the hopper; and good air flow distribution through the hopper.

3.10.2 Opportunities

Gas-fired Dryers:
Several manufacturers offer modular, natural gas-fired dryers and claim energy cost savings from 60-80% over electric systems. Gas-fired heaters may also be retrofitted to existing electric dryers at about 50% of the original price. Mechanically, the units are virtually identical to electric dryers. However, heat exchangers may be employed to maintain proper moisture levels to compensate for water that is generated in the combustion of gas. While capital costs may be slightly higher than electric dryers, manufacturers claim payback periods averaging about twelve months.

Two-Stage Dryers:
Two-stage systems, incorporating a drying oven and a dehumidifier, may be used to dewater hygroscopic resins while raising their temperature for subsequent melt processing. Manufacturers claim such systems are energy efficient, especially if waste heat from one dryer is reclaimed through a heat exchanger and re-used in the second. Two-stage systems can extend the life of dryer components (such as the dessicant in the second-stage dryer).

Smaller Heaters:
Instead of central heating systems, smaller, independently controlled heater elements may be installed in each drying bin, avoiding any energy loss along pipelines or conduits. Other systems combine drying and conveying into a single unit.

Microprocessor Controls:
Drying is another area where the application of microprocessor control can result in significant process improvements. Dryers are often operated at less than their maximum rated capacity using more energy than required to remove moisture. With recently developed microprocessor control, temperature and dewpoint sensors installed at strategic locations in each dryer provide data input to a drying profile programmed for the specific resin being processed. The target profile automatically controls hot air flow, triggers replacement of dessicant cartridges, and maintains the dewpoint and drying temperatures to optimize the actual material throughput and the drying conditions in the unit. However, at its present level of operational reliability, it is wise practice to supplement microprocessor control with periodic manual checks to ensure proper operation.

Insulation:
The hopper or drying bin, as well as any connecting hot air conduits, may be enclosed in an insulating blanket to prevent heat loss.

Energy Recovery:
The heat from the exhaust side of drying bins can be recovered through a heat exchanger and used for: general plant heating, preheating incoming air, preheating material sent to an extruder, or heating material in other drying/dehumidifying bins.

Inspection and Maintenance:
Significant savings may be achieved at little or no cost by following a regular, well-documented maintenance program. Proper maintenance procedures and schedules are generally available from equipment manufacturers. A well documented program would calendarize and coordinate inspection and preventive maintenance of equipment and housekeeping procedures.

3.11 MELT PROCESSING

3.11.1 DESCRIPTION

Thermoplastics are remelted using heat and pressure, filtered to remove any residual contaminants, and used to produce pellets or other products in a standard extrusion system. Extrusion is a process in which a polymer compound is heated, melted and forced through a shaping orifice, or die, transforming the clean flakes into a continuous melt stream. Colourants, fillers, reinforcing

materials and/or processing aids may also be incorporated into the feed prior to extrusion. Whether processing virgin resins or recycling clean scrap, the extruder used is virtually identical.

Although several equipment manufacturers are marketing turn-key plastics recycling systems, most reprocessors have put their recycling lines together using a collection of new, used and refurbished components assembled from various sources. Many reprocessors have purchased their extruders second-hand.

While there are a wide variety of extruders available, the basic system used for reprocessing consists of:

- an extruder, which delivers a homogeneous supply of melted resin at the proper temperature and pressure to the die;
- a melt filtration device (e.g. a hydraulic screen changer)
- a die, through which the resin is extruded in the desired shape;
- a pelletizer; and,
- a cooling stage (employing water baths, sprays or air cooling systems).

The extruder consists of a machine base, a drive (motor, gearbox, thrust bearing), a control cabinet and a plasticating unit (screw and barrel). The latter is the heart of the extruder. Its function is not only to transport, but also to plasticate and compress the polymer. Either a single screw or twin screws pull in resin flakes and transfer them down the barrel from the cooled feed zone towards the heated die end. During their passage down the barrel, external heat, inter-particle friction and shearing, and drag forces melt and mix the flakes creating a homogeneous melt.

Proper screw design ensures that the resin:

- is conveyed at a constant, pulsation-free rate;
- exhibits a consistent temperature and composition;
- is not subjected to conditions that could cause thermal, mechanical or chemical degradation; and
- is processed at a rate that will achieve high through-put at a low operating cost.

The temperature must be carefully controlled in separately heated and cooled zones along the course of the barrel. The temperature control systems commonly used today are: electrical resistance-type heating bands, aluminum jackets with cast-in heating and cooling lines, or other heat conducting media (such as oil, steam or pressurized water) brought into direct contact with the outer wall of the barrel. Sensors are placed in each zone of the barrel (and, in some cases, in the screw as well) to ensure proper temperatures are maintained.

The die will form continuous strands of polymer that may then be pulled through

a cooling tank by the feed rollers of a strand pelletizer, or be cut into pellets directly at the die face. The latter method will use an underwater or water ring pelletizer and will employ a flowing stream of water to cool the pellets.

Water ring and underwater pelletizers generally offer quieter operation and lower maintenance costs than strand cutters. Final selection of the pelletizing system will, however, depend on a number of factors, including production rate, polymer type, and desired pellet geometry.

Heat transferred to the pellet cooling water is typically removed by an evaporative cooling tower.

Melt processing of waste plastics presents special challenges. Washing may not have removed all sources of contamination, such as foil that has been laminated or heat-sealed to plastic. This has to be filtered and removed in the extruder melt stream. High levels of contamination in the recyclate can cause a rise in pressure which will necessitate frequent screen changes and result in increased component costs, labour costs and downtime.

Resin flakes entering the extruder may also be wet and contaminated with residues of volatile printing inks, solvents, adhesives and other resin types. Most extruders are equipped with one or two vents to devolatize the hot melt, draw off the gases generated by the high temperatures achieved, and preserve the quality of the repelletized resin. The off-gases captured may contain thermal degradation products, monomer fumes and other air pollutants. These should be analyzed and may have to be cleaned before release.

Because of the heavy wear and stress on equipment, maintenance costs can be significant in reprocessing facilities, representing five to seven percent (5-7%) of capital costs. In most other kinds of processing plants, they average only two to three percent (2-3%) of capital costs.

3.11.2 Opportunities

New Single Screw Extruders:
A new generation of extruders now commercially available allows for increased barrel length, screw speed and torque, improved drive and transmission, more reliable thrust bearings, efficient barrel venting, closer temperature control, and enhanced shearing and mixing elements. Development efforts are underway to produce more versatile single screw systems that can handle a wider variety of feedstock.

Twin Screw Extruders:
Twin screw systems (either co-rotating or counter-rotating types) force the melt to trace a longer path down the barrel, increasing the shear forces and friction that promote melting. This reduces external heating requirements and can

potentially reduce energy consumption of the extruder by 50-70%. Twin screws also support better feeding and mixing, more precise temperature control, better degassing, higher rpm and shorter residence times, and the gentle heating of sensitive resins. Twin screw extruders of an equivalent size usually provide a higher output and are more versatile than single screw extruders.

On the other hand, twin screw extruders carry a much higher capital cost and entail the use of difficult to accommodate bearings, a complicated gearbox and two screws. The meshing of the screws and the high pressures also give rise to heavy barrel and screw wear. Finally, any solid contaminants remaining in the melt may cause expensive damage to a twin screw system. The decision to switch to a twin screw system must be based, primarily, on processing requirements.

Screw and Barrel Design:
Manufacturers are continually redesigning extruder components for equipment processing “aggressive” resins, such as reinforced polymers or contaminated recyclates. The goal is to construct melt processing systems that operate at higher temperatures and pressures with higher throughput and lower maintenance requirements. Extruder screws and barrels are being manufactured in new configurations and improved alloys to better resist wear and corrosion. Proprietary steel alloys (incorporating tungsten, vanadium, chromium, ceramic and other agents) are being used to form or coat extruder components that can increase corrosion resistance by up to 25-fold, thereby reducing maintenance charges and downtime. Extruder barrel design has also been improved to enhance speed and throughput.

Screen Changers:
Increasingly sophisticated melt cleaning systems are becoming commercially available, including continuous belt, rotary, four-channel and manual slide screen changers. Microprocessors can be used to regulate screen changes only when necessary (i.e., as clogging causes pressure build-up). A small amount of clean melt is then used to backflush the dirty screen and extend filter life.

The recyclate can also be forced through a pair of longer-lasting, laser-cut filters (containing up to 870,000 holes), before the melt travels the full length of the barrel. The filters are cleaned by spring-loaded scrapers and the impurities, such as paper fibre, staples or foil, are fed to a discharge screw. Under normal use, laser filters may need to be replaced monthly, but may be cleaned, recalibrated and reused up to three times.

Turn-Key Systems:
A number of North American and European manufacturers offer turn-key, high efficiency, high volume processing lines for the recycling of PCR and other plastic wastes. While low resin prices and a concurrent slump in recycling interest eliminated some equipment makers, there are a number and variety of systems on the market. Typically, complete systems include bale breaking,

shredding/granulating, metal detection, washing and drying, and hot melt processing components, as well as material handling and conveying equipment.

The use of turn-key systems for reprocessing PCR is often problematic; contaminants can increase wear and abrasion, shortening the useful lifespan of components. A reprocessor considering the purchase of a turn-key system should carefully evaluate the capability of the various components to handle the anticipated feedstock. Expert engineering advice is prudent, either from an in-house or independent outside source.

Energy Conservation:
In order to minimize energy costs, it is important to specify the correct size of motor and gearbox to ensure that motors are running in excess of 80% of nameplate capacity.

Water Conservation:
Heated water from pellet cooling can be reused in upstream washing operations.

3.12 Opportunities For Improving Plant Systems

3.12.1 Motors and Drives

Energy consumption by motors throughout the process is usually the most significant electricity input to plastics reprocessing. The opportunity exists to reduce costs through the installation of high efficiency motors. Advances in high efficiency DC, three-phase AC and brushless DC motors may translate into improved processing control, increased efficiency and lower maintenance costs. Such motors are now widely available. Generally, it is most economic to ensure that high efficiency motors are installed when replacing conventional motors at the end of their useful life. High efficiency motors can achieve savings throughout the process including installation on extruders, grinders, shredders, bale breakers, pumps and blowers, drives, and conveyors. The payback period is especially attractive if the plant operates 3 shifts.

Savings in electricity consumption can also be obtained from motors with varying loads. Quite often, these motors run at full speed even though the throughput rate may be less than design rates. In such cases, variable speed drives (VSD) should be installed. The VSD adjusts the motor speed as the load varies. The difference between full load motor speed and actual lower speed translates into electric power savings. Some examples of VSD applications are pumps, blowers, fans (especially HVAC) and conveyors.

3.12.2 Chillers and Coolers

The process cooling system typically consists of an evaporative cooling tower, circulating pumps and process pumps. The system is used to cool compressors, the extruder barrels and gearboxes, and the resin pellets produced. Some reprocessers, handling resins or systems where lower temperatures are required, may use a refrigerated chiller unit.

Water hardness may be a significant consideration in the operation of a cooling system; precipitated salts can plate dies and contaminate pellets. Chemical conditioning may be used to keep salts from precipitating on system components. Biocides may also be required to control the growth of micro-organisms in cooling water systems.

Free Cooling:
While no process is totally "free," a facility may supplement its electro/mechanical refrigeration systems with evaporative cooling towers. A water/water heat exchanger is used to interface the cooling tower with the existing cooling systems. An evaporative tower using recirculated water can save energy by reducing the load on a chilling system, even in summer, by cooling machine hydraulic systems and compressors. Potential energy savings from free cooling are estimated to be in the range of 50-70% during certain times of the year.

Drives on Cooling System:
Variable speed brushless DC drives, variable speed AC phase inverter drives or high efficiency DC motors offer energy savings of 10-40% over constant speed drives. Variable speed motors/drives fine tune pump and fan speeds (minimizing energy consumption) in accordance with changes in process pressure, flow rates, or water or air temperature requirements, irrespective of the number of machines that are operating. Such drives may be used in conjunction with reciprocating chiller compressor and control systems, circulating pumps, process pumps, cooling tower fans and pumps to achieve energy savings of 10 - 40%.

New High Efficiency Models:
The new generation of chillers on the market claim to cut energy costs by 15-25%. Scroll design units feature no valves, lower compression losses, little heat transfer between suction and discharge gas, and (because there are only two moving parts) low noise and vibration. Energy efficient compressors are available in air- and water-cooled configurations.

Energy Recovery:
Energy costs can be further reduced by using the heated air and/or water produced by cooling equipment. For example, hot air may be used in winter to heat the plant, and hot water to feed heat pumps or used as boiler water feed.

3.12.3 Compressed Air

Compressed air is required for a number of facility operations. Opportunities for conserving air and reducing energy consumption by 5-25% include:

- installing automatic start/stop controls on air compressors to adjust to changes in line pressure requirements (when air demand drops in a facility utilizing a multiple compressor system, it is more energy-efficient to switch off one or more compressors than operate all of them at a lower capacity);
- keeping the pressure in the system as low as possible which also reduces any leak problems;
- cleaning air intake filters;
- piping or ducting cold air from outside to the compressor air inlet (compressor efficiency is reduced 0.3% for every 1° C rise in inlet air temperature);
- eliminating open lines and air leaks in plant (these can occur at hose connections, nozzles, valves, worn cylinders, etc.);
- stopping the inappropriate use of compressed air, e.g. for cleaning floors;
- reducing blowdown time to a minimum through the use and maintenance of condensate traps; and
- recovering waste heat from air compressors for use in another area of the process. For example, it may be practical to use a heat exchanger to transfer heat from the hot air leaving a compressor.

3.12.4 Microprocessor Controls

Microprocessor controls can be applied to individual process steps such as dryers or granulators. As well, centralized microprocessor control may be applied to optimize the entire system to save energy and increase efficiency. This is done by constantly monitoring and adjusting cooling and heated air flow, cooling and wash water flow, and material throughput. Centralized logic controls will manage the input from several dozen sensors on each pump and blower fan, the extruder and material handling systems.

3.13 Package and Ship Resin to Market End-Users

3.13.1 Description

Cooled pellets are transferred from the extruder to a blending silo where they should be thoroughly mixed to ensure homogeneity. A professionally supervised and equipped quality control laboratory is a vital element in maintaining a quality product. The repelletized resins can be handled and used in the same fashion as virgin resins.

Table 4
GENERIC PROCESS AND UTILITY IMPROVEMENT OPPORTUNITIES

Process Area	Opportunity	Section Reference
Receiving & Bale Breaking	• recycling pallets, wrapping, straps, etc. • noise & dust control • specify non-baled feedstock • cover feedstock stored outside to reduce water content • in winter, bring frozen feedstock inside to thaw before debaling	3.1.2 3.1.2, 5.2, 5.6 3.1.1
Inspection & Manual Sorting	• segregation of recyclables	3.2.2
Size Reduction	• improved shredder design • blade design to reduce blade wear • two-stage size reduction • high efficiency motors • microprocessor controls (automatic shut-off, etc.) • noise & dust control • bulk feeding system	3.3.2 3.3.2 3.3.2 3.12.1 3.3.2, 3.12.4 3.1.2, 5.2, 5.6
Ferrous Metal Detection & Separation	• collection & recycling of ferrous scrap	3.4.2
Pre-washing & Granulation	• more efficient grinder designs and models • selecting proper unit size • two-stage size reduction • blade design to reduce wear • granulator maintenance • microprocessor controls (automatic shut-off, etc.) • high efficiency motors • cryogenic grinders • water conservation • noise & dust control	3.6.2 3.6.2 3.6.2 3.6.2 3.6.2 3.6.2, 3.12.4 3.12.1 3.6.2 3.6.2 3.6.2., 5.2., 5.6
Electrostatic, Magnetic & Air-Forced Separation	• collection & recycling of aluminum scrap • separation & recycling of other wastes	3.7.2
Washing, Flotation & Hydrocyclone Separation	• water conservation • counter-current washing • reuse of rinse water • oil/water separation • collection & recycling of other resins • detergent/surfactant recovery	3.8.2, 3.9.2 3.8.2 3.8.2 3.9.2 3.9.2

De-watering/Drying	• use of natural gas dryers or fluidized bed dryers • use of smaller heaters • use of two-stage dryers • microprocessor controls (dewpoint monitors, etc.) • high efficiency motors • wrap dryer in insulating blanket • reclaiming and reusing hot air from dryer • general maintenance on blowers and driers • preventive maintenance on filters, dessicant molecular sieves and heater elements • strip and vacuum diffuser cones • inspect all seals and gaskets • microwave material drying techniques • installation of heat pumps	3.10.2 3.10.2 3.10.2 3.10.2, 3.12.4 3.12.1 3.10.2 3.10.2 3.10.2 3.10.2
Melt Processing	• new single screw designs • twin screw extruders • new turn-key, high efficiency lines • microprocessor controls • melt filtering and screen changers • use of high efficiency motors • reuse of process heat • energy recovery from cooling system • reuse process cooling water downstream • free cooling systems • new high efficiency chillers • maintaining proper melt temperature (reducing auxiliary heating/cooling requirements) • extruder maintenance (addressing screw alignment, screw and barrel wear, etc.)	3.11.2 3.11.2 3.11.2 3.12.4 3.11.2 3.12.1 3.11.2 3.12.2 3.11.2 3.12.2 3.12.2
General Systems	• use of high efficiency motors • variable frequency (speed) drives on pumps and motors • improving efficiency of compressed air system • process optimization using microprocessor controls • power factor improvement • use of portable energy monitoring equipment • improved plant maintenance and housekeeping • plant hygiene and other occupational health and safety concerns • energy efficient lighting • improved heating, ventilation and air conditioning	3.12.1 3.12.1 3.12.3 3.12.4

Table 5

Electric Energy Saving Measures, Extrusion Processing

Process Area	Technology	Potential Energy Savings (%)
Material handling	• properly sized blenders & coolers	30 - 50
	• HE motors on vacuum pumps (5-15HP)	4 - 8
	• HE motors on unloading systems (5-50 HP)	2 - 8
	• HE motors on blowers/fans (5-30 HP)	4 - 8
Granulators	• correct sizing of unit	10 - 30
	• shredder/grinder combo	30
	• HE motors (5-50 HP)	2 - 8
Compressed Air	• auto stop/start controls	10 - 20
	• clean air intake filters	5 - 7
	• duct cold air from outside	5
	• eliminate leakage	10 - 20
	• end inappropriate use	10 - 20
	• reduce blowdown time	5
Material drying	• gas-powered driers	60 - 80
	• dewpoint monitoring	10 - 30
	• microwave drying	50
Extruder	• twin screw	50 - 70
	• insulated barrel	10 - 30
Process cooling	• "free cooling"	50 - 70
	• VSD on chiller compressor	20 - 40
	• VSD on circulating pumps	10
	• VSD on process pumps	20 - 40
	• VSD on chiller compressor	20 - 40
	• VSD on circulating pumps	10
	• VSD on process pumps	20 - 40
	• HE motor on chiller drive (20-100 HP)	1 - 4
	• HE motor on circulating pumps (5-20 HP)	4 - 8
	• HE motor on process pumps (5-50 HP)	2 - 8
Cooling tower	• VSD on tower fans	10 - 20
	• VSD on circulating pumps	10
	• VSD on process pumps	20 - 40
	• VSD drive on tower fans	10 - 20
	• VSD drive on circulating pumps	10
	• VSD drive on process pumps	20 - 40
	• HE motor on tower fans (5-20 HP)	4 - 8
	• HE motor on circulating pumps (5-20 HP)	4 - 8
	• HE motor on process pumps (5-50 HP)	2 - 8

(Note, energy demand will vary greatly, depending on plant design, equipment age and type, feedstock(s), and production rates. The estimated savings are not additive and are for illustrative purposes only.)

(Acronyms: HE — high efficiency; HP — horsepower; VSD — variable speed drive)

4.0 UNIT PERFORMANCE RATIOS

Performance ratios are useful in assessing a facility's efforts to reduce energy and water use, and effluent discharges. A series of generic formulae for calculating these ratios is presented here.

Establishing a baseline measurement of resource consumption and waste output allows a company to evaluate the improvements made in operations and equipment over time. Unit performance ratios are also show how well a company compares to others in terms of inputs and outputs, and highlight areas where there may be opportunities for improvement. However, caution must be exercised in such comparisons to ensure similar activities and processes are included in the calculations. There is a wide range in the energy requirements and water consumption in the operation of reprocessing plants. For example, the amount of water used by the wet granulator, wash tank(s), extruder (to cool the barrel) and pelletizer (to cool the pellets), together, can vary from 3 to 6 litres per kilogram of resin recycled.

The performance ratios here calculate both the process and non-process consumption of energy and water use (including utilities devoted to lighting, heating, ventilating and air conditioning). All can be calculated from utility bills. Any improvements made within a facility will result in a decrease compared to the benchmark.

Unit Electrical Energy Use

$$\frac{\text{Total kWh electricity consumed over 12 months} \times 3.6}{\text{Total kg resin output produced over same 12 months}} = \text{Unit Electrical Energy Use in MJ/kg}$$

Unit Natural Gas Energy Use

$$\frac{\text{Total m3 natural gas used over 12 months} \times 37.2}{\text{Total kg resin output produced over same 12 months}} = \text{Unit NG Energy Use in MJ/kg}$$

Unit Water Use

$$\frac{\text{Total m3 water used over 12 months}}{\text{Total kg resin output produced over same12 months}} = \text{Unit Water Use in m3/kg}$$

5.0 PROCESS RESIDUALS

Although levels of some process residuals are and will continue to be regulated by law to meet established limits, more responsibility is being placed on generators to examine their total emissions and reduce their residuals as good business practice. Voluntary programs that would be relevant to plastics reprocessors include Ontario's "Pollution Prevention Pledge Program" (P4) and the Canadian Council of Ministers of the Environment "Environmental Guideline for the Reduction of Volatile Organic Compound Emissions from the Plastics Processing Industry". Information on these programs is available from the MOEE Pollution Prevention Office.

5.1 AIR CONTAMINANTS

Reprocessors deal with finished plastics either as industrial scrap or post-consumer waste. Usually, these are stable, high molecular weight polymers and do not pose a direct threat to human health or the environment. Under normal operating conditions, reprocessing facilities do not create a substantial risk of exposure to the low molecular weight building blocks of plastic resins. Caution must be exercised, however, to ensure that thermal degradation of the polymer, additives or contaminants does not cause emissions at a level that is an occupational, health or environmental concern.

Liberation of thermal decomposition products to the workplace or surrounding environment is most likely to occur during melt processing in the extruder. The highest concentrations of offending gases will be found at the extruder vent, screen changer and die. The possibility of noxious gas generation from hot air dryers should not be overlooked.

A chemical inventory and an air sampling survey, should be included as part of an in-plant resource audit to determine sources of air contaminants that may need to be addressed.

Engineering controls, including adequate ventilation, should be implemented to ensure that workplace air levels of any contaminants comply with Ontario's occupational standards under the regulations of the Occupational Health and Safety Act. In addition, workers should have access to (and instruction in the proper use of) personal protective equipment. However, the use of such equipment cannot be relied on to meet the regulated exposure limits.

A Certificate of Approval, issued by the MOEE is required for any facility that discharges a contaminant into the natural environment (i.e. outside a building). Application for a Certificate of Approval must be made prior to commencing operations. Information on the requirements for applying for a Certificate of Approval may be obtained from the Regional Office of the MOEE.

5.2 Dust Control

Dust can be liberated during unloading, material handling, bale breaking, conveying, air-blown separation of contaminants, hopper and additive mixing operations, pelletizing and packaging of recycled PCR.

Fine dust can pose a respiratory threat to exposed workers. Inhalable particles can also provide a pathway into the body for contaminants that may be present on or in the resins. Finally, dry mixing and pelletizing may generate levels of combustible plastic dusts that pose an explosion threat.

Proper operations and control can ensure that dust levels are not a problem at reprocessing facilities.

5.3 Odour Problems

The decomposition of food scraps and other organic wastes contaminating post-consumer resins can generate ammonia, hydrogen sulphide, mercaptan, amine and other especially odiferous gases, fumes and aerosols. Volatile compounds that exhibit a strong odour can also arise during the melt processing of certain resins.

While there is a wide range in individual sensitivities to odiferous compounds, many of the most disagreeable can be detected and recognized at levels as low as a few parts per million. In addition to their negative impact on the workplace environment, they also have a tendency to move readily beyond a facility's property line to arouse the attention of neighbours.

Odour problems can be difficult to control or eliminate, and the consequences of unresolved emissions should not be minimized. An odour control system will require a Certificate of Approval if there is a discharge to the atmosphere.

5.4 Wastewater Residuals

Wastewater is generated in the operation of the: wet granulator, wash tank, hydrocyclone, centrifugal dryer, hot air dryer, extruder and pelletizer. Potential wastewater problems include high biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS).

Wash and rinse water from the washing systems may contain fines, fibres, soils, dissolved solids, product residues, emulsified oils, detergents and surfactants. Appropriate treatment for process and discharge waters may include filtration, chemical flocculation, and/or neutralization. Such treatment may result in opportunities for reusing part of the wastewater stream within the process.

5.5 Solid Waste Residuals

Some reprocessors, particularly those that handle PCR and other contaminated feedstock, have to deal with large volumes of waste. Contaminants removed during or subsequent to size reduction may include:

- dirt, stones, glass, etc.
- product residues (food and other organic wastes, oil, etc.)
- other resins (caps, lids, labels, other packaging components)
- ferrous scrap (caps, lids, etc.)
- aluminum scrap (caps, lids, etc.)
- paper pulp (labels, etc.)

Other materials routinely employed, consumed or otherwise used in the reprocessing of plastics in a manner likely to generate sludge, wastewater or solid wastes may include:

- detergents and surfactants, used in the pre-wash and wash stages;
- replacement parts (cutting blades, etc.) for the shredders, granulators and other size reduction equipment;
- flocculants and other water treatment chemicals;
- air filters;
- oil filters, lubricating oils, etc. associated with power transmission or engine maintenance;
- additives, colourants, anti-oxidants and other chemicals that may added to the reprocessed resins; and
- cleansers and general plant maintenance chemicals.

Solid wastes, not directly related to the recycling process, generated at a facility may include:

- fine office paper (invoices, reports, correspondence, computer print-out, etc.)
- newsprint, magazines and lower grade paper;
- old corrugated containers;
- empty bottles and cans (glass, steel, plastic, aluminum);
- cafeteria/lunch room food wastes; and
- grass clippings and other landscaping wastes.

Solid waste totals range from a low of 5% of the delivered feedstock to as high as 25% (this latter likely includes the weight of skids, wrappings and other shipping materials). Much of this material is recyclable. For example, at the large Canadian Polystyrene Recycling Association facility, about 65% of the solid waste generated, including cardboard cartons, wooden skids and stretch wrapping, is recycled and 35% is sent for disposal. Information on reducing and recycling general, non-process waste is widely available from municipal public works departments or the MOEE Public Information Centre.

5.6 Noise Levels

Many municipalities maintain and enforce noise by-laws. The control of noise pollution is an important consideration during shredding and cutting operations. A double angle cutting mill when processing film or foam will produce noise levels in the 80 to 85 decibel range. When cutting tougher, more resilient feedstock, noise levels may rise to 110 decibels.

Noise reduction measures may involve encapsulating the shredding/granulating equipment in an insulated box, or segregating this operation in a separate insulated room, and feeding scrap via a sound insulated hopper. These measures can reduce noise levels by 30 to 35 decibels. Staff must also be equipped and instructed in the proper use of hearing protection equipment appropriate to the expected noise levels.

5.7 Health and Safety Concerns

The provision and use of hard hats, ear and eye protection, proper gloves and protective clothing are mandatory in most reprocessing facilities. Staff that handle "sharps" or contaminated PCR should also be inoculated against hepatitis B infection. Reprocessors should contact the Ministry of Labour concerning occupational health and safety requirements, including worker training.

6.0 NEW TECHNOLOGIES

6.1 Automatic Sorting

Success in segregating mixed resins, separating coloured materials and removing contaminants makes the difference between producing high value resins that can compete with virgin supplies and lower value material.

Automatic and continuous sorting systems would increase the efficiency and cost-effectiveness of both MRFs and commercial reprocessors that handle mixed resins. Labour costs of manual sorting is the single biggest cost in plastics recycling. Improvement in sorting technology could also broaden the range of resins that could be collected in curbside and IC&I waste diversion programs. A more effective sorting technology could also improve a reprocessor's ability to remove trace levels of contaminants and achieve tighter quality specifications for the recycled resins.

While a number of technical problems still need to be resolved, separation systems that have been considered or are currently in various stages of development, include:

- improvements to hydrocyclones being carried out at Michigan State University Department of Chemical Engineering;
- Float/sink systems using different specific gravities in the liquid phase;
- optical sensors used to detect differences in the light transmitted, absorbed or reflected by different resin types and/or colours, with air jets or other mechanisms used to separate contaminants;
- optical readers used before baling to recognize definitive container shapes, universal product codes (UPC) or other distinctive markings;
- a laser detector that recognizes the characteristic thickness of products;
- a number of systems that rely on X-ray, near and far infrared (IR) or ultra-violet (UV) sensors to detect variations in the electromagnetic radiation exhibited by various resin types;
- systems that incorporate a combination of sensors to detect variations in visible, UV, IR and/or other wavelengths;
- the incorporation of fluorescent "tag" molecules into virgin resins that can be read at a later date by a sensor at the recycling centre;
- the separation of flakes of PVC/PET, mixed in a fluidized bed, based on differences in their electrostatic properties;
- heated conveyors to which resins with low melting points adhere and from which more heat resistant resins can be easily removed; and
- the solvent-based separation of ground resins based on differences in their dissolution properties at different temperatures.

Barriers being investigated these new sorting systems include high capital cost, maintenance and operator costs and environmental implications of systems such as solvent extraction. EPIC is the best industry source for information on the status of such new technologies.

6.2 Processing Improvements

At first glance, an extruder from thirty years ago looks much like one made today. However, equipment manufacturers and industry groups are continually introducing innovations to improve the efficiency, durability and versatility of the components used as part of a plastics processing line. Research, pilot and field studies are directed at developing:

- improved, energy efficient shredding and (wet) grinding equipment;
- more durable, longer-lasting blades, knives, barrels, screws, screens, screen changers and other components;
- more efficient air classification systems for removing contaminants from granulated feedstock;
- improved microprocessors to provide continual feedback on processing and initiate timely adjustments to temperature, flow rates, etc.;
- energy efficient motors and drives;
- new gas-fired, microwave, fluidized bed and high efficiency electric drying units;
- more versatile single and twin screw extruders;
- turn-key, high efficiency reprocessing lines;
- new chilling systems and process cooling improvements;
- systems to reuse process heat, cooling water and/or wash water;
- extrusion pulverizing (producing easy-to-blend powders at room temperature); and
- briquetting (compacting powdered resins into pellets).

The breadth of options for processing improvements is broad. There is no one source that provides a completely comprehensive pool of information. Reprocessors are advised to source information through vehicles such as trade shows, industry journals and publications and contact with manufacturers.

6.3 Process Monitoring

In-line process monitoring can be used to measure and closely control material properties, energy and water use, and other parameters during the extrusion process. Optical analysis technology is being evaluated in a pilot project at the University of Toronto. It would permit the measurement of mixture composition, colour and particle content in a process stream.

6.4 Compatibilizers and Additives

Compatibilizers are high performance polymers that may be used to process polymer waste or commingled plastics that cannot be separated readily. The compatibilizer promotes chemical bonding between the different polymers in the mixed recyclate to form a stable and, hopefully, marketable resin product. However, compatibilizers are expensive and don't tend to produce a value-added product, that is, one that exceeds the sum of the values of the individual polymers. Both proprietary and non-proprietary compatibilizers are being developed and tested.

Research is currently under way in Ontario to develop a low cost reactive compatibilization process effective in both twin and single screw extruders. The technology is based on vector fluids, and has been successfully demonstrated at the laboratory scale.

6.5 Advanced Gas-Fired Pulsed Fluid Bed Dryers

This technology is based on a modified fluid bed dryer. It is still under development in Canada but is scheduled to be commercially available by the end of 1997. The new dryer is expected to have lower capital and operating costs compared to conventional dryers due to its smaller size and lower pressure/volumetric flow rate. More uniform drying improves product quality. Testing has shown energy efficiency improvements when drying polypropylene, polystyrene and rubber flakes. A significant advantage of this technology is its ability to dry different size plastic particles simultaneously.

6.6 Microwave Drying

These units, which dry material using conventional microwave technology, are still under development. Their main advantage is reduced drying time, allowing more rapid material turnover and lower energy costs. However, the technology is capital intensive and prototype units are batch-oriented. Most reprocessors operate continuous feed systems. Further development will be required to make microwave technology widely accepted for this application.

6.7 Depolymerization & Energy-From Waste

Advances are being made not only in primary recycling techniques, but more complex secondary and tertiary recycling processes — such as glycolysis, hydrolysis, methanolysis, pyrolysis, gasification and hydrogenation — that break complex polymers down into monomers or further, to their petrochemical feedstock, for reformulation or energy use.

These technologies have received attention because they do not require that feedstock be presorted into separate resin groups or colour types, and there are established markets for the end products if contamination levels fall within specified levels. Huge volumes of plastic waste are required to allow these facilities to be viably operated using known technology. While investigations continue in bench, pilot or full-scale facilities across North America, no facilities are currently under consideration or development in Ontario.

With the removal of the ban on new municipal incinerators in Ontario, there is renewed interest in so-called quaternary recycling, or energy-from-waste initiatives. There are few technical limitations to the use of plastics in these facilities. The choice of whether to adopt this option as part of a waste management system lies with municipalities and private sector proponents after consideration of what constitutes the best use of resources.

EPIC is a reliable source of technical information in this area.

7.0 Other Helpful Information

A series of additional reference materials about energy and environmental improvements in plastics reprocessing are described in the following sections. In most cases, contacts are provided for acquiring follow up information.

7.1 Plastics Reprocessing References

- ***Electrical Efficiency Opportunities in the Plastics Processing Industry in Ontario***, Canadian Plastics Institute, 1993. This study approximates the distribution of energy used in various process technologies and identifies energy savings techniques that can be readily adopted, often without major expenditures on equipment.

- ***Energy Conservation in the Plastics Processing Industry in Canada***, Energy, Mines and Resources Canada, 1983. Guidance to processors for establishing successful energy conservation programs, and information on trends in energy use, new and emerging conservation technologies, potential savings and implementation costs.

- ***Waste Plastics: Collection, Sorting & Pre-Processing***, Canadian Plastics Institute, 1990. This document provides an overview of legislative trends in North America and Europe, as well as processing technologies (sorting, washing and granulation, de-watering and drying, melt processing, solvent separation, chemical recycling, etc.); a good overview on plastics reprocessing.

- ***Plastics Recycling: Products and Processes***, Society of Plastics Engineers. A comprehensive survey of the technical, business and environmental components involved in the recycling of plastics (including, PET, polyolefins, polystyrene, polyvinyl chloride, engineering thermoplastics, acrylics, commingled plastics, and thermosets).

7.2 Associations/Agencies

- **Environment and Plastics Industry Council.**
EPIC was formerly known as the Environment and Plastics Institute of Canada and is now a Council of the Canadian Plastics Industry Association. It provides a wide range of general information about integrated resource management and plastic solid waste issues. Other resources include technical reports and information for solid waste managers about plastics recycling collection and sortation methods. EPIC can be reached in Mississauga at (905) 678-7405, fax (905) 678-0774.

- **Canadian Plastics Industry Association**
The Canadian Plastics Industry Association is the voice of the plastics industry in Canada. CPIA delivers its services through regional offices and can be a valuable source in the areas of technology, trades, health and safety and the environment. The National Office of CPIA is located at 5925 Airport Road, Suite 500, Mississauga, Ontario, L4V 1W1, telephone (905) 678-7405. CPIA, Ontario Region is located at 365 Bloor Street East, Suite 1900, Toronto, Ontario M4W 3L4, telephone (416) 323-1883, fax (416) 323-9404.

7.3 Industry Directories/Guides

- Environment and Plastics Institute of Canada. 1995. ***Plastics Recycling Directory***. Provides a listing and cross indexing of the participants in all aspects of plastics recycling in Canada including processors, equipment suppliers, services and associations. Available from EPIC at (905) 678-7405.

- Ontario Ministry of Environment and Energy. 1996. ***Directory of Ontario Green Industries***. This directory provides a listing and description of over 2,000 Ontario suppliers of pollution prevention, pollution control and remediation equipment. The index is cross referenced by environmental specialty. Contact the MOEE Public Information Centre for copies at 1-800-565-4923 or (416) 325-4000.

- Industrial Gas Technology Commercialization Center. 1996. ***Natural Gas Plastic/Polymer Process Equipment Guide***. Discusses the applications of new natural gas equipment for air compressors, central thermal fluid systems, dessicant air dryers and resin dryers. Available from the Industrial Center at (703)841-8463.

- Natural Resources Canada. 1994. ***CEMET Resource Catalogue:*** List and description of available energy efficiency products and services. For information, contact NRCan at (613) 995-6839.

7.4 Environmental/Resource Audit Guidance Documents

- Harmony Foundation of Canada. 1991. ***Workplace Guide - Practical Action for the Environment.*** This guide was developed to introduce methods for implementing environmentally sustainable practices in industry. It describes tools to be used by organizations to assess environmental strengths and weaknesses, develop a strategic plan and implement improved environmental practices, including resource conservation. It offers a comprehensive step-by-step approach to help identify both economic and environmental benefits through positive thinking, serious commitment and cooperative action. Copies may be obtained from the Harmony Foundation of Canada, 1183 Fort Street, Victoria, British Columbia, V8V 3LT. telephone: (250) 380-3001, fax: (250) 380-0887, email: harmony@islandnet.com.

- National Round Table on the Environment and Economy. 1991. ***Decision Making Practices for Sustainable Development.*** This book provides a template for organizations implementing environmental management strategies. Assistance in making critical corporate environmental choices and decisions by providing effective checklists

such as the Business Code of Practice Strategy Checklist for decision makers who want to incorporate sustainable development considerations in their organizational decisions. Procter & Gamble Inc.'s experience in developing their corporate environmental strategy is provided as a case study. Copies may be obtained from the National Round Table on the Environment and the Economy, 1 Nicholas Street, Suite 1500, Ottawa, Ontario, K1N 7B7, telephone (613) 992-7189.

- Natural Resources Canada. Efficiency and Alternative Energy Program. ***A Manager's Guide to Creating Awareness of Energy Efficiency.*** Provides an outline of a program for communicating and involving employees in energy management programs in the workplace. The document includes a disk of prepared communications articles and graphics. Copies may be obtained from Natural Resources Canada at (613) 995-6839.

- Natural Resources Canada. Efficiency and Alternative Energy Program. 1994. ***Technical Information***. The information is a technical bibliography and a compendium of technical factsheets on topics relating to energy conservation in buildings. Copies may be obtained from Natural Resources Canada at (613) 995-6839.

- Canadian Industry Program for Energy Conservation. ***CIPEC Energy Efficiency Planning and Management Guide.*** This guide provides information on how to establish an effective energy management program. It includes a series of worksheets outlining practical measures in various energy consuming areas of industrial operations. CIPEC also provides a range of services to assist companies improve their energy performance. For further information and copies of the CIPEC Guide, contact the CIPEC Secretariat at (416) 798-8155 or by fax at (416) 798-9174.

- Canadian Standards Associations. 1994. ***Environmentally Responsible Procurement*** ("Green Procurement"). Z766-94. Call toll free to order: 1-800-463-6727.

7.5 Pollution Prevention Guidance Documents

- Ontario Ministry of Environment and Energy. 1993. ***Pollution Prevention Planning: Guidance Document and Workbook***. PIBS 2586E. ISBN 0-7778-1441-2. The workbook introduces pollution prevention planning and implementation concepts and principles; offers a model/approach to initiating team planning exercises and provides worksheets and checklists for implementation. Contact the MOEE Public Information Centre for copies at 1-800-565-4923 or (416) 325-4000.

- Canadian Standards Associations. 1994. ***Guideline for Pollution Prevention***. Z754-94. Call toll free to order: 1-800-463-6727.

7.6 Environmental Approvals and Certificates

- Ontario Ministry of Environment and Energy. MOEE Approvals Branch. 1995. Approvals Functions. A guide to applying for Certificates of Approval to operate. Available from and Ministry Regional or District Offices listed in the blue pages of the telephone book.

8.0 GUIDE REFERENCES

Defining a Plastics Diversion Strategy, A Report by the Ontario Plastics Strategy Team, Ontario Ministry of Environment and Energy, Toronto, ON, April, 1994

Electrical Efficiency Opportunities in the Plastics Processing Industry in Ontario, Canadian Plastics Institute & SNC Lavalin Inc., prepared for Ontario Hydro (Report TDD-93-005), Toronto, ON, February, 1993.

Energy Conservation in the Plastics Processing Industry in Canada, The Society of the Plastics Industry of Canada and Energy, Mines and Resources Canada, (Industry Series, Publication #18), Ottawa, ON, February, 1983

Plastics Processing: An Introduction, Walter Michaeli, Hanser Publishers, Hanser/Gardner Publications Inc., Cincinnati, OH, 1995

Plastics Recycling: Product and Processes, R.J. Ehrig (editor), Hanser Publishers, Oxford University Press, New York, NY, 1992.

Plastic Recycling Technologies Seminar, Canadian Plastics Institute, Etobicoke, ON, 1994

Plastics Waste Management: Disposal, Recycling and Reuse, Nabil Mustafa (editor), Marcel Dekkar Inc., New York, NY, 1993

Post-Consumer Polyolefin Plastic Recycling: The Resource Plastics Inc. Experience, J.T. Horn, prepared for the Ministry of Environment and Energy, Toronto, ON, September, 1995

Waste Plastics: Collection, Sorting & Pre-Processing, Canadian Plastics Institute, prepared for Environment and Plastics Institute of Canada, Etobicoke, ON, January, 1990

APPENDIX I - SOURCING RAW MATERIALS

There are two primary sources of feedstock resin for reprocessing — the industrial, commercial and institutional (IC&I) sector and the residential sector.

A significant fraction of the waste generated by industrial formulators and manufacturers of plastic products is industrial scrap which is reground, melted and reused on site. Some is available for off-site recycling. Other plastics recycled from the IC&I sector include: transport packaging such as polystyrene foam, crates and shrink and stretch wraps, bulk packaging materials such as pails, drums and film bags, and, automotive casings.

Plastics commonly available from municipal recycling programs are plastic bottles and jugs, plastic film, polystyrene containers and wide-mouth containers. As of 1996, more than 3.4 million households in 520 communities (comprising approximately 80% of the households in Ontario) had access to curbside or "blue box" recycling programs. In turn, there were 51 MRFs handling, sorting and baling the materials collected from municipal recycling programs. The separated resins are made available to plastics reprocessors as raw materials.

The types of post-consumer resins available from individual municipalities vary widely. Table A shows the number of households that have collection available to them for various resin types. Detailed information on plastic materials available from municipal recycling programs is available from the Recycling Council of Ontario (see Section I.2)

Table A[2]

ONTARIO HOUSEHOLDS WITH ACCESS TO PLASTIC RECYCLING PROGRAMS, 1996

Material	# of Households with Collection	Percentage of Households with Access to Recycling
PET	3,437,711	100
Rigid Plastics	2,677,806	78
Plastic film	1,204,074	36
Polystyrene	1,088,592	32
Polycoat milk and juice containers	1,119,198	33

There are a number of vehicles available to reprocessors to access sources of resin. Some of these sources are described below.

I.1 CANADIAN WASTE EXCHANGES

The Environment and Plastics Industry Council (EPIC) is lending financial and technical assistance to the Waste Exchanges across Canada to increase the recycling of plastics. The role of the exchanges is to identify potential users of a variety of wastes and to match those users to the generators of such waste. There are eight non-profit waste exchanges operating in Canada, seven regional exchanges (in Alberta, Atlantic Canada, British Columbia, Manitoba, Quebec, Ontario and Saskatchewan), plus the national Canadian Waste Materials Exchange (CWME).

[2] Extracted from the Recycling in Ontario Report. January, 1996. Ontario Multi Material Recycling Institute.

Canadian Waste Exchanges	
Canadian Waste Materials Exchange 2395 Speakman Drive, Mississauga, ON L5K 1B3 Tel: 416-822-4111, ext. 265 Fax: 905-822-7630	Ontario Waste Exchange 2395 Speakman Drive, Mississauga, Ontario L5K 1B3 Tel: 905-822-4111, ext. 358/658 Fax: 905-822-7630
Alberta Waste Materials Exchange Action on Waste 9915-108 Street, 12th floor, South Petroleum Plaza Edmonton, T5K 2G8 Tel: 403-422-2179 Fax: 403-427-1594	Bourse Québécoise des Matières Secondaires 900 Place de Youville, Suire 210, Québec, PQ G1R 3P7 Tel: 418-643-0394 Fax: 418-643-5607
Manitoba Resource Conservation 2-70 Albert Street, 2nd Floor, Winnipeg, MB R3B 1E7 Tel: 204-925-3777 Fax: 204-942-4207	British Columbia Waste Exchange Recycling Council of B.C. 201-225 Smithe Street, Vancouver, BC V6B 2X7 Tel: 604-683-6009 Fax: 604-683-7255
Atlantic Coastal Action Program (ACAP) P.O. Box 6878, Station A, Saint John, NB E2L 4S3 Tel: 506-652-2227 Fax: 506-633-2184	Saskatchewan Waste Materials Exchange Saskatchewan Research Council 515 Henderson Drive, Regina, SK S4N 5X1 Tel: 306-787-9800 Fax: 306-787-8811

For plastic reprocessors, the local waste exchange may be able to identify alternative sources of materials as well as end users for their process byproducts such as recovered metals.

I.2 Recycling Directories

Access to information on the recycling industry and markets for all recyclable commodities in Ontario can be obtained through the Recycling Council of Ontario (RCO) (416) 960-1025. The RCO has compiled a waste management information software package called 3RSource that is updated semi-annually. This package provides profiles on municipal programs, recycling markets, curbside data, associations, products, suppliers, references and current events. The cost is $200 for RCO members and $260 for non-members.

General information on recycling in municipalities can be obtained from the Association of Municipal Recycling Councils (AMRC) at (519) 823-1990. The

AMRC also operates a bulletin board for markets and related information at (519) 823-1188.

EPIC has published the "1995 Plastics Recycling Directory" which references companies involved in plastics recycling in Canada. Companies are cross indexed as to capabilities, resins handled, recycled content products supplied and by geographical location. Other information in the directory specific to the plastics recycling industry includes recycled material suppliers, recycling equipment suppliers, collectors/waste haulers, consultants, service organizations and a plastics products source directory. Copies of the directory can be ordered from EPIC by faxing EPIC at (905) 678-0774.

I.3 Chicago Board of Trade (CBOT) Recyclables Exchange

The CBOT Recyclables Exchange is an innovative approach for plastics reprocessors to find sources of supply and end markets for their products. The concept is based on the original Chicago Commodities Exchange introduced in the 19th century to stabilize the volatile market for corn and agricultural products. In this 21st century model, the exchange is a "virtual" commodities marketplace that operates electronically. Buyers and sellers of recyclable materials from municipal and industrial collection programs can list their commodity with an expected price, quantity and an ability to meet CBOT specifications. The CBOT exchange guarantees and will certify trades of materials listed on the exchange. Materials accepted for listing includes those typically found in North American recycling programs such as plastics (PET and HDPE only at this time), newspaper and other fibres, glass in various conditions, ferrous metals and alumimium. The CBOT currently has both a phone-in service for trades and an internet address. For further information and access to the CBOT bulletin board, call (312) 986-9780. Web site access is via WWW.CBOT.COM and look for "ecocentre".

APPENDIX II - GLOSSARY

Acronyms

ABS	acrylonitrile butadiene styrene
AC	alternating current
BDC	brushless direct current
CPI	formerly Canadian Plastics Institute, now Canadian Plastics Industry Association
CPIA	Canadian Plastics Industry Association
CPRA	Canadian Polystyrene Recycling Association
DC	direct current
EPA	Environmental Protection Act
EPIC	formerly Environment and Plastics Institute of Canada, now Environment Plastics Industry Council
EPS	expanded polystyrene
GPPS	general purpose polystyrene
HE	high efficiency
HDPE	high density polyethylene
HP	horsepower
HVAC	heating, ventilation and air conditioning
IC&I	industrial, commercial and institutional
LDPE	low density polyethylene
LLDPE	linear low density polyethylene
MOEE	Ministry of the Environment and Energy
MRF	material recycling facility
MSW	municipal solid waste
PC	polycarbonate
PCR	post-consumer resin
PE	polyethylene
PET	polyethylene terephthalate
PIR	post-industrial resin
PP	polypropylene
PS	polystyrene
PVC	polyvinyl chloride
3Rs	reduce, reuse and recycle
RCO	Recycling Council of Ontario
SPI	Society of the Plastics Industry of Canada, now CPIA
VSD	variable speed drive

Glossary

Automatic Separation
Innovative sorting technology is being developed and refined to separate mixed plastic waste streams by colour and/or major resin type, as well as remove non-plastic contaminants. Several automatic systems are now offered commercially.

Commingled Plastics
A mixture of two or more different types of plastic materials. Technology now exists to recycle some commingled plastics into useful products.

Contaminant
Foreign materials (such as dirt, organic waste, oil or the residues of the contents of plastic containers) that make it more difficult to recycle a plastic feedstock and reduce or eliminate the value of the derived post-consumer resin.

Degradable Plastics
Plastics specifically developed or formulated to break down after exposure to sunlight or microbes. Complete degradation has not been achieved at current levels of development.

Energy Recovery
A process that extracts energy value from a substance such as air, water or solid waste and transfers it to another medium to be used again. Examples are heat recovery from exhaust streams to preheat incoming air or burning solid waste as fuel to generate heat.

IC&I Solid Waste
Industrial, Commercial and Institutional solid wastes generated by businesses and industries (including shopping centres, restaurants and offices) and institutions (such as schools, hospitals and government offices). IC&I wastes comprise approximately 60% of Ontario's total municipal solid waste stream.

Manual Separation
Hand sorting is widely used (at the point of generation or material recycling facility) to separate plastic wastes by resin and/or colour.

Material Recovery Facility (MRF)
An intermediate facility where curbside collected mixed recyclables are processed into individual streams such as paper fibre, glass, metals, and plastics for market.

Monomers
The basic chemical building blocks used to create plastic polymers (long chain molecules).

Off-Spec Resin
Any resin that does not meet its manufacturer's specifications, but may still be offered for sale.

Ontario Regulation 347
Waste Management — General Regulation 347, under Ontario's Environmental Protection Act, sets out standards for solid waste disposal sites and waste management systems, and governs the handling, transport and disposal of registerable liquid industrial and hazardous wastes.

Plastics
Synthetic materials consisting of large polymer molecules derived from petrochemicals or renewable sources. Plastics are capable of being shaped or moulded under the influence of heat, pressure or chemical catalysts. Polymer resins are often combined with other ingredients, including colourants, fillers, reinforcing agents and plasticizers, to form plastic products.

Plastics Recycling Coding System
This is a voluntary marking system for plastic containers to identify material type. The purpose of coding is to assist recyclers in sorting plastic containers by resin composition. The system uses a triangular- shaped symbol found on the bottom of the container. The symbol is composed of three arrows with a number in the centre indicating the type of resin used to make the container.

Plastic Resin
A synonym for "polymer".

Polymer
A very long chain molecule built up by repetition of small chemical units, known as monomers, strongly bonded together.

Post-Consumer Resin (PCR)
PCR is manufactured from used plastic materials or products, generated by consumers in homes, offices, commercial outlets, and institutions, which have been diverted from the waste stream and recycled into a form suitable for reprocessing into new products. PCR is distinct from Post-Industrial Resin.

Post-Industrial Resin
Plastic scrap, trim, shavings, grindings and damaged materials generated by a processor or fabricator that are reground on-site and reused directly in the process that generated them. Also known as Pre-Consumer Resin.

Primary Recycling
Relatively clean and segregated plastic scrap are processed into new products with properties similar to those of the original resin.

Quaternary Recycling
The energy content of plastics is recovered by burning them in an energy-from-waste facility.

Recyclable
According to labelling guidelines developed by Consumer and Corporate Affairs Canada, a product or package is deemed "recyclable" where at least 35% of the population across Canada has convenient access to collection or drop-off facilities for recycling that material. Where a material or product cannot be or is not reasonably expected to be recycled, no claim of recyclability may be made.

Recycling
A process by which post-use materials (i.e. those materials that can no longer be used for their intended purposes) are separated from the waste stream, collected and processed for transformation into new products.

Residential Solid Waste
The waste produced by all kinds of households, including detached dwellings, row housing, condominiums and apartments. In Ontario, residential waste makes up about 40% of the total municipal solid waste stream.

Reuse
The direct reapplication of a material in its original form for either the same or a different purpose. It can apply to packaging materials or process inputs such as water.

Secondary Recycling
Turns mixed or contaminated plastic scrap into new materials with properties that differ from those of the original plastic resins.

Separation
Division of wastes into groups of similar materials (either mechanically or manually). Potentially recyclable rigid plastic packaging has been coded to support the separation process.

Source Reduction
The elimination, avoidance or reduction of pollution and waste at the point it is generated by using raw materials, energy, water and other resources more efficiently and by redesigning manufacturing processes and products.

Source Separation
The segregation of used materials from municipal waste into specific material categories at the point of generation in order to facilitate recycling.

Tertiary Recycling
Commingled or single resin plastic scrap is broken down into its basic monomers or hydrocarbon constituents, which can then be used as chemical feedstock or raw material to make new resins.

Thermoplastics
Plastic resins that can be repeatedly softened by heating, shaped by flow into articles by molding or extrusion, and hardened.

Thermosets
Plastic resins that are hardened or "cured" by an irreversible chemical reaction which creates strong cross-links between the polymer molecules. Once formed, thermosets cannot be remelted without degrading the resin.

Three Rs (3Rs)
The reduction, reuse and recycling of waste.

Virgin Materials
Any raw material intended for industrial processing which has not been previously used.